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COVER
A view of the northwest part of Montagu Island, taken from the balcony of the lighthouse. The rounded granite outcrops characterise the southern section of the island; the northern part is underlain by basaltic rocks. The vegetation is dominated by *Lomandra longifolia* with patches of *Phragmites australis* where drainage is impeded. In the foreground *Lomandra* tussocks stand out among *Pennisetum clandestinum*, an introduced grass prevalent along the path that leads to the jetty. A breeding colony of Silver Gulls is in the foreground.

Photographer: Petrus C. Heyligers, October 1993

Allan Cunningham, botanist and explorer (1791–1839)

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Flora and vegetation of Montagu Island – past and present

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Abstract: Montagu Island (36°15'S; 150°14'E) is situated about 10 km east of Narooma on the New South Wales South Coast. The paper presents evidence about the changes in the terrestrial vegetation of the island since it was first seen by Europeans, provides a floristic inventory and gives a perspective on the effects of introduced species.

Flinders (1814) mentions that the island 'produced small trees.' This is the only record of what grew on the island until in 1880 annotations on a map, made at the time of the construction of the lighthouse, mentioned the presence of scrub, trees and rank grass. This is confirmed by photographic evidence, but by 1932, when the botanist F. A. Rodway visited the island, the trees had disappeared. In 1973, during a land use survey of the South Coast, a team of CSIRO described the vegetation as a distinct series of dune communities belonging to the *Lomandra longifolia – Pteridium esculentum – Phragmites australis* complex. Vegetation mapping in the late 1980s confirmed the prevalence of these species, except that *Pennisetum clandestinum* then covered a large area along the west side of the island.

Excluding taxa used for ornamental or culinary purposes, nearly 200 species of vascular plants have been recorded since 1932 of which about 140 were still present in the late 1990s. There are ten species of ferns e.g. *Pteridium esculentum*, widespread and sometimes codominant with *Lomandra longifolia*, and *Asplenium obtusatum*, frequently found among the rocks along the east side of the island. The only taxon unique to Montagu Island is a hybrid of this species and *Asplenium australasicum*. Among the flowering plants there are about 110 native species and about 70 species naturalised in Australia. About 85 and 40, respectively, are still present today. Many of these have a wide distribution in Australia and only about 25 have a more restricted coastal distribution. The species that have disappeared include many that were weeds in the vegetable gardens or around the chicken sheds. Several naturalised species still present are notorious for their capacity to overrun existing vegetation. Foremost among these is *Pennisetum clandestinum*, which now covers about one-third of the island; *Acetosa sagittata* is a close second. Other contenders are *Dipogon lignosus* and *Delairea odorata*. It is now apparent that these species were kept in check by the feral goats that roamed the island before it was declared a Nature Reserve in December 1987.

***Cunninghamia* (2004) 8(3): 285–305**

Introduction

Montagu Island (36°15'S; 150°14'E) is situated about 10 km offshore from Narooma on the New South Wales South Coast. It has a north-south orientation, is nearly 2 km long, up to about 700 m wide and reaches an elevation of about 50 m asl (Fig. 1). Seen from an approaching ship, the lighthouse, together with large rounded rock outcrops set in a low vegetation of green and reddish brown hues, dominates the scenery. In 1790 the master of the supply ship 'Surprize' discovered that Cook's 'Cape Dromedary' was actually an island and named it after George Montagu Dunk, Earl of Halifax (Reed 1969). This name, together with the Aboriginal name Barunguba, is still used on the charts published by the Admiralty. The spelling 'Montague Island,' sanctioned by the Geographical Names Board of New South Wales, originated from a mistake on Flinders's chart (Flinders 1814).

The aim of the paper is to document what is known about the terrestrial vascular flora of Montagu Island. It presents evidence about changes in the vegetation since the island was first seen by Europeans, updates and expands earlier papers (Heyligers & Adams 1989, Heyligers 1993) and provides a perspective on the effects of introduced species at a time that considerable changes in flora and vegetation can be expected as a consequence of the management regime implemented by NSW National Parks and Wildlife Service.

Environmental factors: climate, geology and soils

The Narooma area (average annual rainfall 887 mm) is a relatively dry region in comparison with other areas in coastal southern New South Wales. Median annual rainfall is only 803 mm with annual extremes between 426 and 1769 mm (Kalma & McAlpine 1978). Average rainfall on Montagu Island is 909 mm per year, while the median value is 908 mm. Monthly averages range from 122 mm in March and 118 mm in June to 49 mm in July and 60 mm in August. Rainfall data for the mainland show a moderate summer maximum, but no such trend is apparent in the data for Montagu Island. Average maximum and minimum temperatures for February, the warmest month, are 23.6 and 17.8°C, those for July, the coldest month, 15.3 and 9.7°C (Anon. 1988). Minimum temperatures below 6.0°C are rare; however, on 22 July 1983,

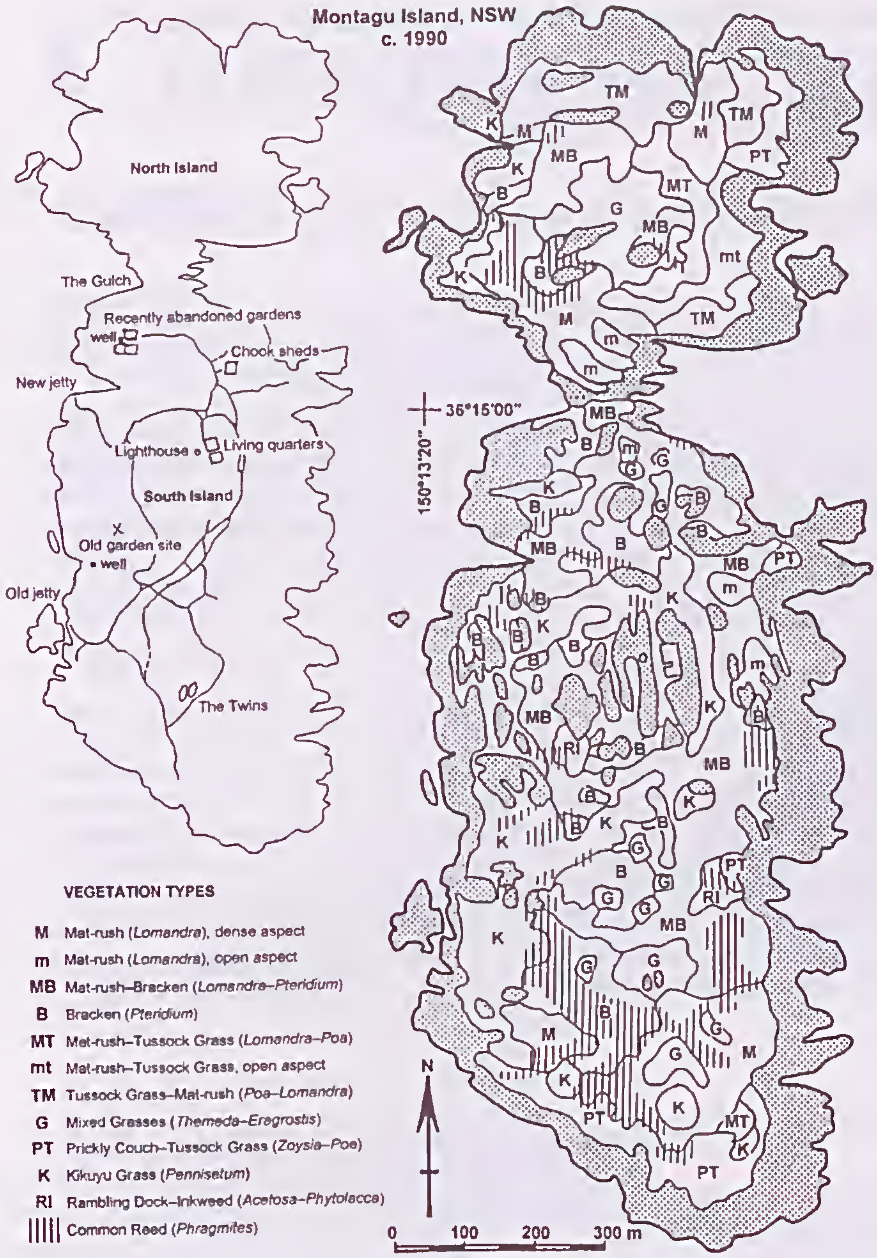

Montagu Island, NSW
c. 1990
North Island
The Gulch
Recently abandoned gardens
well
Chook sheds
New jetty
Lighthouse
Living quarters
South Island
Old garden site
well
Old jetty
The Twins
36°15'00"
150°13'20"
VEGETATION TYPES
M Mat-rush (*Lomandra*), dense aspect
m Mat-rush (*Lomandra*), open aspect
MB Mat-rush–Bracken (*Lomandra–Pteridium*)
B Bracken (*Pteridium*)
MT Mat-rush–Tussock Grass (*Lomandra–Poa*)
mt Mat-rush–Tussock Grass, open aspect
TM Tussock Grass–Mat-rush (*Poa–Lomandra*)
G Mixed Grasses (*Themeda–Eragrostis*)
PT Prickly Couch–Tussock Grass (*Zoysia–Poa*)
K Kikuyu Grass (*Pennisetum*)
RI Rambling Dock–Inkweed (*Acetosa–Phytolacca*)
|||| Common Reed (*Phragmites*)
N
0 100 200 300 m

Fig. 1. Montagu Island as it was in the late 1980s. Vegetation and major rock outcrops (stippled) are shown at the right, buildings and other features, including tracks, at the left. (The vegetation map is based on Heyligers 1993 with permission from the Eurobodalla Natural History Society, the map with geographic features on Fullagar & Heyligers 1992.)

when in the screen a minimum temperature of 6.6°C was recorded, there was 'frost on island near chookpen' according to an annotation in the logbook.

The island's northern section is shaped by basaltic rocks, its southern by granite (Brown 1930). The junction between the two rock types formed a zone of weakness and has eroded to below present-day sea level. The gap between the sections is variously known as 'The Gulch,' 'The Gorge' or 'The Gut.' It is filled with large boulders, but at the western side a beach of shellgrit connects the northern section, usually called 'North Island', with the southern one, about twice as large and known as 'South Island.' North Island is plateau-like with a gently bulging centre. It has steep slopes at the western side and cliffs at the eastern and southern sides. The northern and north-eastern sides of South Island are also steep, but the remainder is fringed by staggered, shelving rock platforms giving way to large, rounded outcrops towards the crest. Joints formed lines of weakness and have eroded into cliff-sided canyons cutting into the periphery of the island.

Soils on the island are invariably coarse-textured as they have developed in wind-blown sands overlying bedrock. They are moderately deep, medium acid throughout and imperfectly drained. Their colours grade from black to very dark grey in the surface horizons to dark brown or reddish brown beneath (Gunn 1978). Coffee-rock, a dark reddish brown massive hardpan cemented by iron and organic compounds due to impeded drainage, occurs at variable depths and in its turn provides another impermeable layer.

European history of the island

In the early 1880s a lighthouse was built on the highest rock outcrop of the South Island (Higgins 1990, Pacey 2001). After Federation the island came under the jurisdiction of the Commonwealth and in 1953 was gazetted as a Wildlife

Reserve to protect seabirds breeding on the island and seals hauling out on the rocks along the northern shore. After automation of the light in the 1980s, the jurisdiction over the island was transferred to the State of New South Wales and it became a Nature Reserve administered by the National Parks and Wildlife Service (Pacey 2001). This resulted in a drastic change in management regime. Under Commonwealth rule the lightkeepers, although adapting to changing circumstances in the outside world, lived by and large in traditional style and the management of natural assets was largely a matter of laissez-faire (Higgins 1990). The only livestock kept on the island at the time of the transfer were chickens. Horses, pigs, sheep, milking goats, dairy cows, geese and ducks were already a thing of the past, but goats had turned feral and rabbits, already introduced to the island before the lighthouse was built, were still present. So were some of the courtyard and outside gardens, which were used for growing ornamental plants as well as vegetables (Pacey 2001). When the National Parks and Wildlife Service took over, an active natural resources management regime was put in place, which started with the immediate eradication of the goats. However, no special efforts were made to eradicate the rabbits, as these were already subject to periodic outbreaks of myxomatosis. Recently, experiments have been put in place to push back invasive introduced plant species and establish a cover of native species instead (N. Klomp, pers. comm.).

Methods

To discover the history of vegetation change an extensive search for early descriptive and photographic material was undertaken in libraries and archives in the late 1980s and early 1990s. This search was underpinned by information presented by Higgins (1990) and Pacey (1991). In addition, we visited people who had ties with Montagu Island and were able to help with information and often with photographs as well. These sources are documented in the Acknowledgements.

The species list in our earlier paper (Heyligers & Adams 1989) was updated with later collections made by Heyligers, while identifications, where necessary, were checked and names brought up to date by Adams. Also, the computer databases at the Australian National Herbarium (CANB) and at the National Herbaria of New South Wales (NSW) and Victoria (MEL) were searched for collections from Montagu Island. As not all collections in these herbaria have as yet been entered, we expect that in due course some further collections will come to light. Details on distribution for plant-geographic analysis were obtained from Jacobs and Pickard (1981), Harden (1990–1993) and Walsh and Entwisle (1994–1999), while field experience and field notes were used to assess abundance and habitat preferences on the island. Nomenclature follows Harden (1990–1993), and Walsh and Entwisle (1994–1999) for later changes.

Early botanical records

Montagu Island has a long history of use by indigenous people (Pacey 2001) and this may well have had a profound influence on the vegetation. Flinders (1814) mentions that the island 'produced small trees,' but this is the only record of what grew on the island in the early days of colonisation. A map of South Island, made at the time the lighthouse was built, has annotations about topography and vegetation: 'Scrub Trees and rank Grass,' 'Scrub and Trees,' 'Scrub and Stunted Trees,' 'Coarse rank Grass' (Anon. 1883).

A.F. Basset Hull (1908) walking up from the jetty at the western side of South Island to the lighthouse in September 1907 described the vegetation as: 'A few very ragged and dwarfed banksias (*Banksia integrifolia*) and Pigeon-berries (*Monotoca elliptica*) scattered at wide intervals, were the only trees on the island, but the sandy soil between the granite boulders was thickly overgrown with masses of the red-flowering pea-creeper (*Kennedia rubicunda*). Under these creepers, tangled up with tussock grass, rushes and stinging nettles, the Penguins' runs and burrows extended in every direction.'

Higgins (1990) consulted much primary source material such as newspaper articles and lightkeepers' logbooks and found that in newspaper reports from the late 19th century 'island oaks' were mentioned as well as remarks on the disappearance of 'the historic Bear.' From this one may assume that casuarinas and, if the bear is indeed a koala, eucalypts were present on the island.

In May 1921 F. A. Rodway, a medical practitioner and keen amateur botanist living in Nowra, asked the Montagu lightkeeper for a sample of the island flora. The lightkeeper, M. A. Williams, obliged by sending samples of ten species and in the covering letter wrote: 'There is not much variety, in fact the Island is practically covered with the ordinary coastal tussock' (Rodway archive: Royal Botanic Gardens, Sydney). Rodway sent one of the creepers to the Government Botanist, J.H. Maiden, for identification and received the following answer dated 30 June, 1921.

> Dear Dr. Rodway,
>
> The climber with opposite leaves appears to be *Marsdenia rostrata*, but flowers are required to confirm the determination. The flora of the small islands which skirt our coast are worthy of record, imperfect as the present collection obviously is. It seems desirable that a botanist should visit as many of these islands as possible; if that cannot be done, then it is desirable that local residents should do the work as well as they are able. As, so far as I am aware, no note has been made of the vegetation of Montague Island, I will cause a note of them to be put in the Australian Naturalist, if you approve.
>
> Yours faithfully,
>
> (J. H. Maiden.)

However, no such note was published until eleven years later after Rodway had visited Montagu Island on 4 April 1932 (Rodway 1932). In his diary Rodway listed 46 species of which he made collections. Twelve of these were introduced.

His annotations are scant and mostly refer to 'foliage' or 'old flowers.' However, *Kennedia rubicunda* is 'luxuriant,' and *Phytolacca octandra* 'plentiful, luxuriant.' There were only a 'few plants, S. end' of *Monotoca elliptica*, from which only 'foliage' was collected (and hence, earlier mis-identified as '*Leucopogon Richei*'). In 1953 there was still one 3 m high *Monotoca elliptica* left, the only tree present on the island (Higgins 1990). '*Phragmites communis*' occurred in '2 patches in wet places on S. portion.' *Stenotaphrum secundatum* was found 'at landing place & at lighthouse.' This species had been introduced in 1916 to develop lawns around the quarters to prevent further erosion of the sandy soils (Higgins 1990). Rodway's other notes refer mostly to the plants cultivated by the keepers; however, he also saw 'a few rotten stumps of *Banksia* (?) *integrifolia*' and 'a photo of opening of lighthouse [in 1881] showing a large *Banksia*,' while 'one of staff said a small wattle tree on the Island.' Most likely this referred to an *Acacia longifolia* var. *sophorae* shrub (Rodway archive; Royal Botanic Gardens, Sydney).

Some of the remarks Tom Paddon, keeper from 1934 to 1937, made during a taped interview in 1979 are relevant here: 'There used to be big trees all over the island … then they introduced the rabbits to the island and the rabbits undermined all the trees and they fell over….' 'I've seen stumps 3 ft across, big trees of all kinds….' 'There was only one tree (when he was there), what we'd call a blackwood tree, that the goats used to nibble the bark off … leaves … killed everything' (L. Pacey pers. comm. 1992).

Early photographic evidence

The lighthouse was built at a time when photography had come 'of age.' Pacey (1991) shows several early pictures from which some information on the vegetation can be gained. Further searching has uncovered more pictures, including panoramic views taken from passing ships. All of these confirm that trees were present on both North and South Island, but they generally appear to be stunted and at best to occur in small groups (Fig. 2). A photograph similar to the picture referred to by Rodway indeed shows branches of a *Banksia integrifolia* (Fig. 3), but species recognition on other photographs is at best guess work (Fig. 4). Also, shrubbery was widespread. On the pictures bushes appear compact and sometimes wind-shorn. Again, species identification is impossible (Fig. 5). However, *Lomandra longifolia* was undoubtedly an important component of the ground cover, but generally appears to be interspersed with other herbaceous vegetation. Later photographs attest to the gradual disappearance of the woody plants; for instance, a picture of the lighthouse taken around 1900 shows that the *Banksia integrifolia* tree was no longer there. A couple of *Metrosideros excelsa* trees now occupy that position (Fig. 3).

Basset Hull (1914) took pictures of Silver Gull (*Larus novaehollandiae*) colonies, then located on North Island, showing a herbaceous vegetation outside the colonies, most likely dominated by *Lomandra longifolia* (Fig. 6). In 1990 the positions from which the three published photographs were taken, were relocated. Silver gulls no longer breed there, but the aspect of the vegetation had hardly changed. Even the rock fragments lying on a gently sloping rock outcrop were still in the same position.

Oblique aerial views of Montagu Island taken in 1936 by Stanley Fowler of CSIRO's Fisheries Investigation Section, leave no doubt that by that time all trees had gone and that only a few patches of shrubbery remained (Figs. 7 and 8). They also show widely spaced *Lomandra longifolia* tussocks, and vegetable gardens on the west side of South Island at a site since overrun by *Pennisetum clandestinum*.

Later botanical work

Little botanical activity took place between 1932 and 1973, when in April a team of CSIRO's Division of Land Use Research visited the island for two days. The floristic inventory was carried out by L.G. Adams; 44 collections were made and many more species were listed. Austin and Sheaffe (1976) characterised the vegetation as follows:

> A distinct series of dune communities [belonging to the *Lomandra longifolia – Pteridium esculentum – Phragmites australis* complex] occurs on Montague Island. The island is covered with drifted sand to varying depths. These communities, dominated by *Lomandra longifolia*, appear to reflect both the disturbance and eutrophication effects of the bird colonies and the soil moisture drainage patterns across the underlying rock. They form a complex continuum along an apparent moisture gradient from *Lomandra* dominated areas to those dominated by *Phragmites australis*.

In the early 1960s it was discovered that three shearwater species, the Wedge-tailed Shearwater (*Puffinus pacificus*), the Sooty Shearwater (*Puffinus griseus*) and the Short-tailed Shearwater (*Puffinus tenuirostris*) bred on Montagu Island (Fullagar 1973). Since breeding success of these species has been monitored annually in late March by teams of volunteers (Fullagar et al. 1991). On most occasions since 1988 P.C. Heyligers has been a member of this team, and during these visits and additional ones in the spring he mapped the vegetation and documented the flora by collecting voucher specimens. Heyligers and Adams (1989) published a floristic inventory for the island based on collections and observations up to and including 1988, whilst Heyligers (1993) published a map, which recorded the distribution of the vegetation in the late 1980s. During four transect surveys in the 1990s to assess the population size of Little Penguins (*Endyptula minor*), dominant plants were recorded, in addition to nesting details. This information, together with additional fieldwork, has been used by Trezise (1999) and Weerheim et al. (2003) to assess the spread of *Pennisetum clandestinum*.

We have not found any publication on the marine algae of Montagu Island. However, since 1995 Dr Alan Millar of the Royal Botanic Gardens, Sydney, has collected many

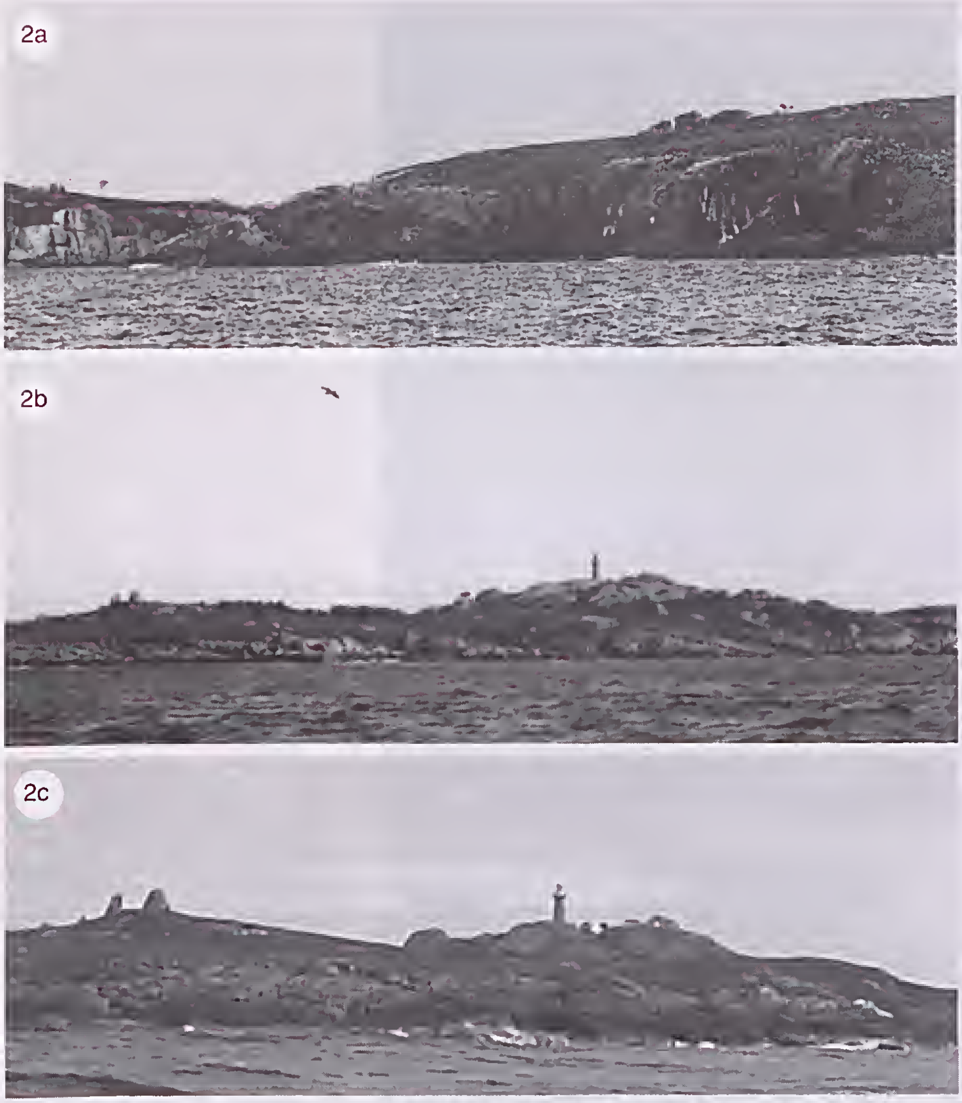


Fig. 2. Views of the east coast of Montagu Island, taken from coastal steamers shortly after the lighthouse was built compared with 1988.

(a) Shows a stand of trees on the highest part of North Island. (Detail from a photograph in A. Searey's SLA: PRG 280/1/ 'Albums of photographs of Australian Scenes' p. 17 (1902), used with permission of the State Library of South Australia.)

(b) Shows stands of woody vegetation and an isolated tree in the area between The Twins and the lighthouse. (Detail from a photograph taken around the turn of the century held by, and used with permission from, the State Records of New South Wales, catalogued as CGS 4483 Glass Negatives 1870–1988 [Aperture Card no. 1994.)

(c) Picture taken in 1988.

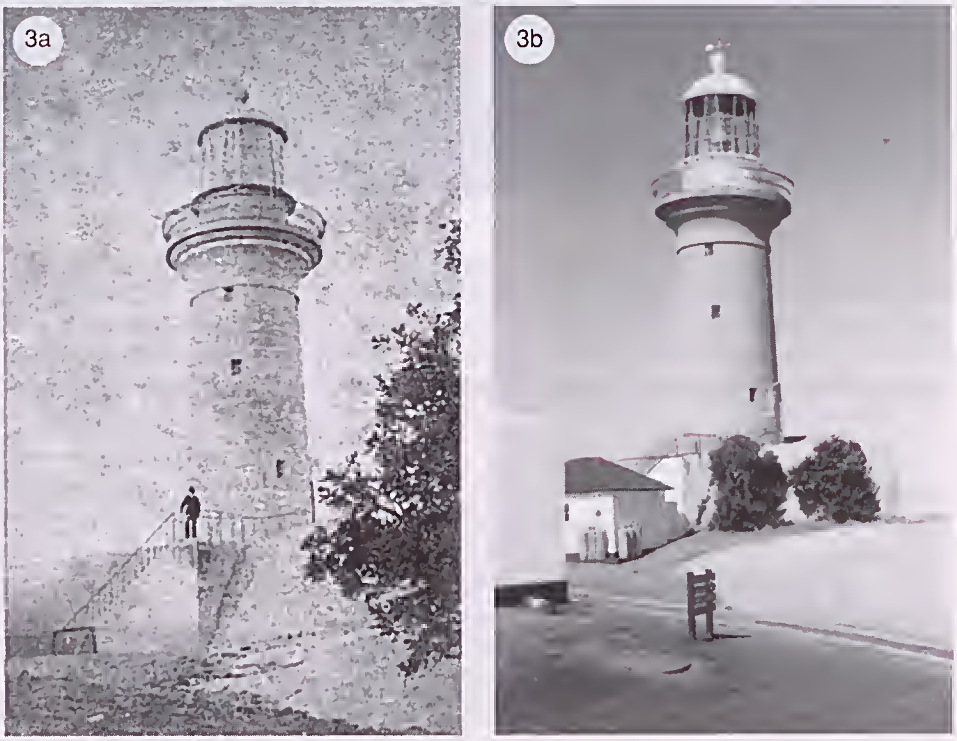


Fig. 3. The picture on the left (a) (courtesy of Mrs B. Debus), taken shortly after the lighthouse was opened in 1881, shows branches of a *Banksia integrifolia* tree. During the next fifty years all trees disappeared and during his visit in 1932 Rodway saw only a few rotten stumps, possibly from banksias.

The *Metrosideros excelsa* trees on the photograph at the right (b), taken in 1993, now grow on about the same spot as the banksia. Pohutakawas, or New Zealand Christmas trees, were introduced to the island in the early 1960s.

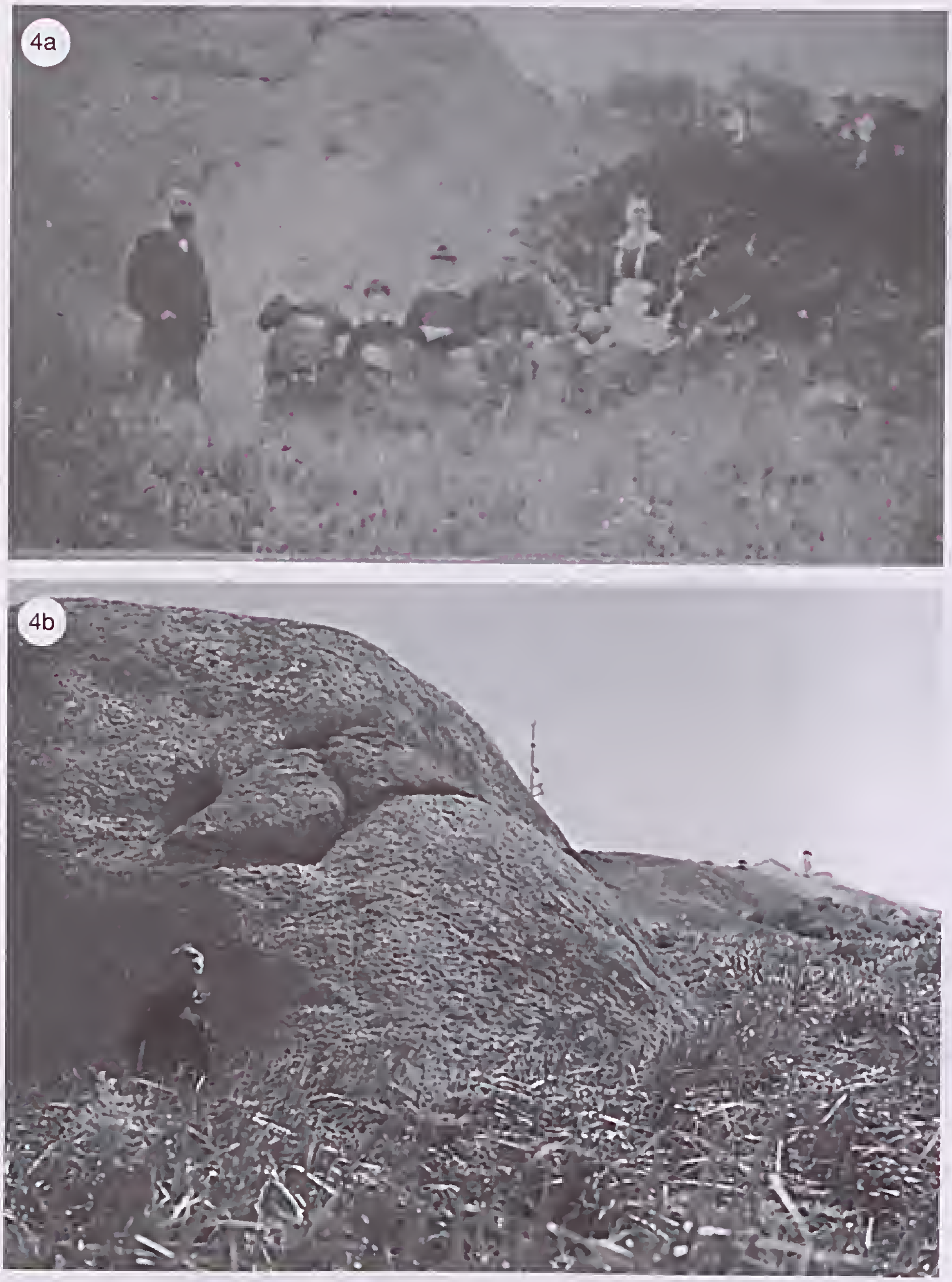


Fig. 4.

(a) A photograph taken in 1882 (courtesy Mrs B. Debus) against the background of an isolated rock outcrop south-west of the lighthouse quarters features members of head lightkeeper John Burgess's family seated on what appears to be the flattened trunk of a windshorn tree, with more trees in the background. Unfortunately, species identification is at best guess work.

(b) In 1993 the vegetation surrounding this outcrop was dominated by *Lomandra longifolia*.

specimens around the island but a good deal more taxonomic work needs to be done before the results are ready for publication (Millar, in lit. 2003).

The present vegetation of Montagu Island

Dominant communities

After the disappearance of most woody plants, a few herbaceous species, notably *Lomandra longifolia*, *Pteridium esculentum* and *Poa poiformis*, became the dominant elements in the vegetation (Heyligers 1993). The map depicting the situation at the end of the 1980s (Fig. 1) shows that seven mapping units were based on differences in the co-dominance of these three species and the overall density of the vegetation, the height of which is generally between 0.8 m and 1.2 m. Besides the dominant species, the twiners *Marsdenia rostrata* and *Kennedia rubicunda* are locally common and, in more open vegetation, *Isotoma axilaris* and *Einadia hastata* are frequently seen. *Solanum vescum* occurs as scattered individuals and reaches a height of about 1.5 m. In places there is a groundcover of *Commelina cyanea*. *Phragmites australis* occurs as an added element where drainage is impeded by the configuration of the underlying impermeable substrate. This species may be found in unexpected situations, for instance near the crest of North Island.

On some Victorian, Tasmanian and Western Australian islands with breeding colonies of little penguins and short-tailed shearwaters, marked effects on the vegetation have been found, characterised by an increase of succulent plants at the expense of species like *Lomandra longifolia* and *Pteridium*

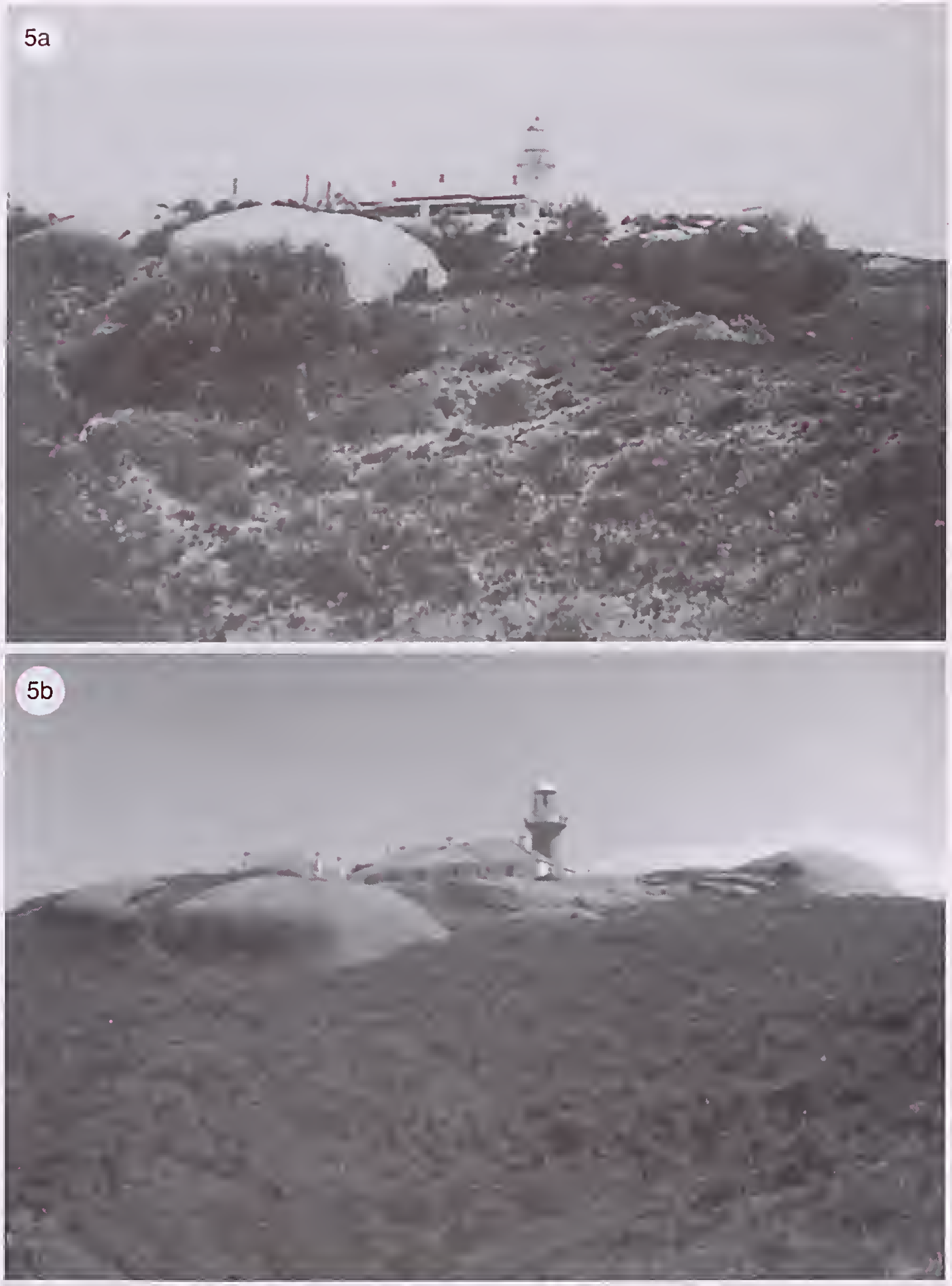


Fig. 5.

(a) In the early days shrubbery was widespread, as shown on this picture (courtesy Ms L. Pacey) of the area to the northeast of the lighthouse quarters.

(b) This area is now dominated by dense *Lomandra longifolia* vegetation.

esculentum which occur in the undisturbed dune vegetation (Gilham 1960, 1961, Rippey et al. 2002, Walsh et al. 1997). We have observed this phenomenon on Gabo Island, but the only effect we have noticed on Montagu Island is that, due to nitrification, the grass around penguin burrow entrances, along paths with a cover of regularly mown *Pennisetum clandestinum*, is often greener than elsewhere. This may be due to chicks spending time at the entrance rather than to adults, which defecate when preening after leaving the water and during their long hikes over the rocks before they reach the vegetation.

The very shallow soils found over and among fractured rock outcrops on higher parts of the island carry a lower, more mixed vegetation, in which, apart from *Lomandra longifolia*, *Pteridium esculentum* and *Poa poiformis*, grasses such as *Themeda triandra*, *Eragrostis leptostachys*, *Imperata cylindrica* and *Zoysia macrantha*, and the sedge *Isolepis nodosa* can be found. The only *Ozothamnus diosmifolius* shrub on the island occurs in this vegetation. *Crassula sieberiana* and the ferns *Cheilanthus austrotenuifolia* and *Cheilanthus sieberi* grow in small crevices of the rocks.

Vegetation dominated by *Zoysia macrantha* and *Sporobolus virginicus* occupies a wide fringe at the southern end of South Island, which is often subject to heavy saltspray. It also occurs in smaller patches elsewhere on the east side of both North and South Island. This vegetation is low, rather carpet-like and interspersed with many small rock outcrops (Fig. 9). *Lobelia alata*, *Dichondra repens* and *Tetragonia tetragonioides* occur scattered amongst the grasses. The name used for the mapping unit, namely *Zoysia–Poa*, would be more

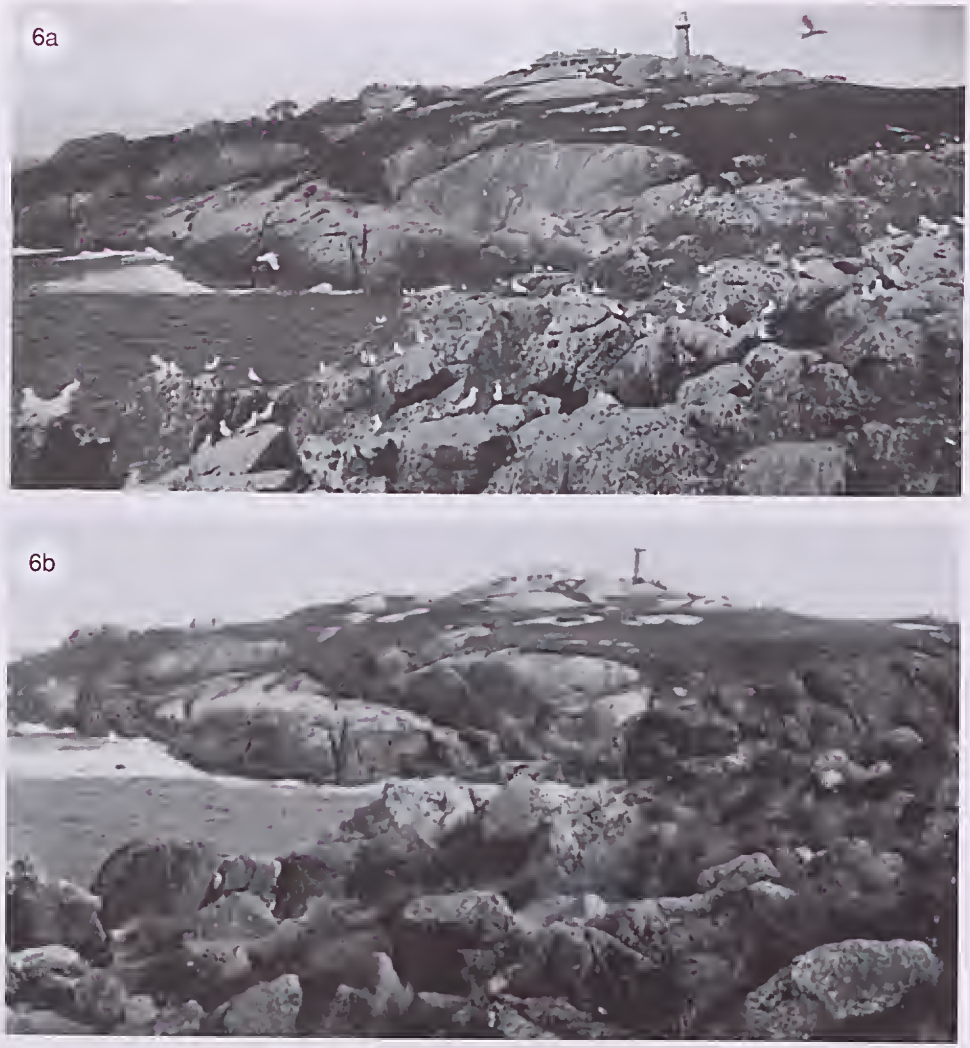


Fig. 6.

(a) Basset Hull (1914) took pictures of silver gull colonies, then located on North Island, which show little vegetation among the rocks. (Reproduced from the first issue of *Australian Zoologist*, with permission from the Royal Zoological Society of New South Wales.)

(b) Now the luxuriant vegetation is dominated by *Lomandra longifolia*. Some rocks in the foreground have broken up, while the trees on the distant skyline have gone.

appropriate for these smaller areas where patches of *Poa poiformis* and *Isolepis nodosa* are more prevalent.

In 1990 vegetation dominated by *Pennisetum clandestinum* occurred at several locations on the western side of the island. Patches on North Island were small, but on South Island *Pennisetum clandestinum* covered a considerable area that extended to the crest along the tracks leading up from the old and new jetties. Around the lighthouse complex it mixed with or replaced *Stenotaphrum secundatum*. One of the lightkeepers, who did several tours of duty between 1970 and 1986, 'has noticed just how rapidly the kikuyu has taken over on the island. He recalled none at the southern end of the island earlier' (Higgins 1990). In 1990 *Pennisetum clandestinum* vegetation occupied 16% of the vegetated area of the island (Fig. 10). However, as was to be expected (Crooks & Soulé 1999), released from grazing pressure of the goats, *Pennisetum clandestinum* spread even more rapidly and by 2001 covered an area of 37% (Weerheim et al. 2003). This process may have been assisted by intensified track maintenance. While previously tracks were merely rough paths through the *Lomandra*-dominated vegetation (Fullagar pers. comm.; Fig. 7), when the island was foreshadowed to become a Nature Reserve and a tourist destination, the vegetation on the tracks was at first regularly slashed and when *Pennisetum clandestinum* became establised, mown. It is likely that *Pennisetum clandestinum* seeds and stolon fragments were spread through these activities.

Another mapped category is vegetation dominated by species which take hold after severe disturbance, the more important of these being *Acetosa sagittata* and *Phytolacca octandra*, together with *Solanum chenopodioides*, *Urtica incisa*, *Commelina cyanea*, and twiners, especially *Stephania japonica*. In 1990, on the east side of South Island, there was a large patch at the rear of a cove, where some years before the vegetation was killed by a seawater surge through the cove. It is now dominated by *Pennisetum clandestinum*.

Minor communities

There are various minor vegetation communities on the island, occupying only small areas due to specific habitat requirements and too small to be mapped. Examples include beach vegetation, stands of *Stipa stipoides* on the margin of high cliffs, shrub communities on cliff faces, areas influenced by groundwater seepage and the vegetation of small bodies of water in rock hollows.

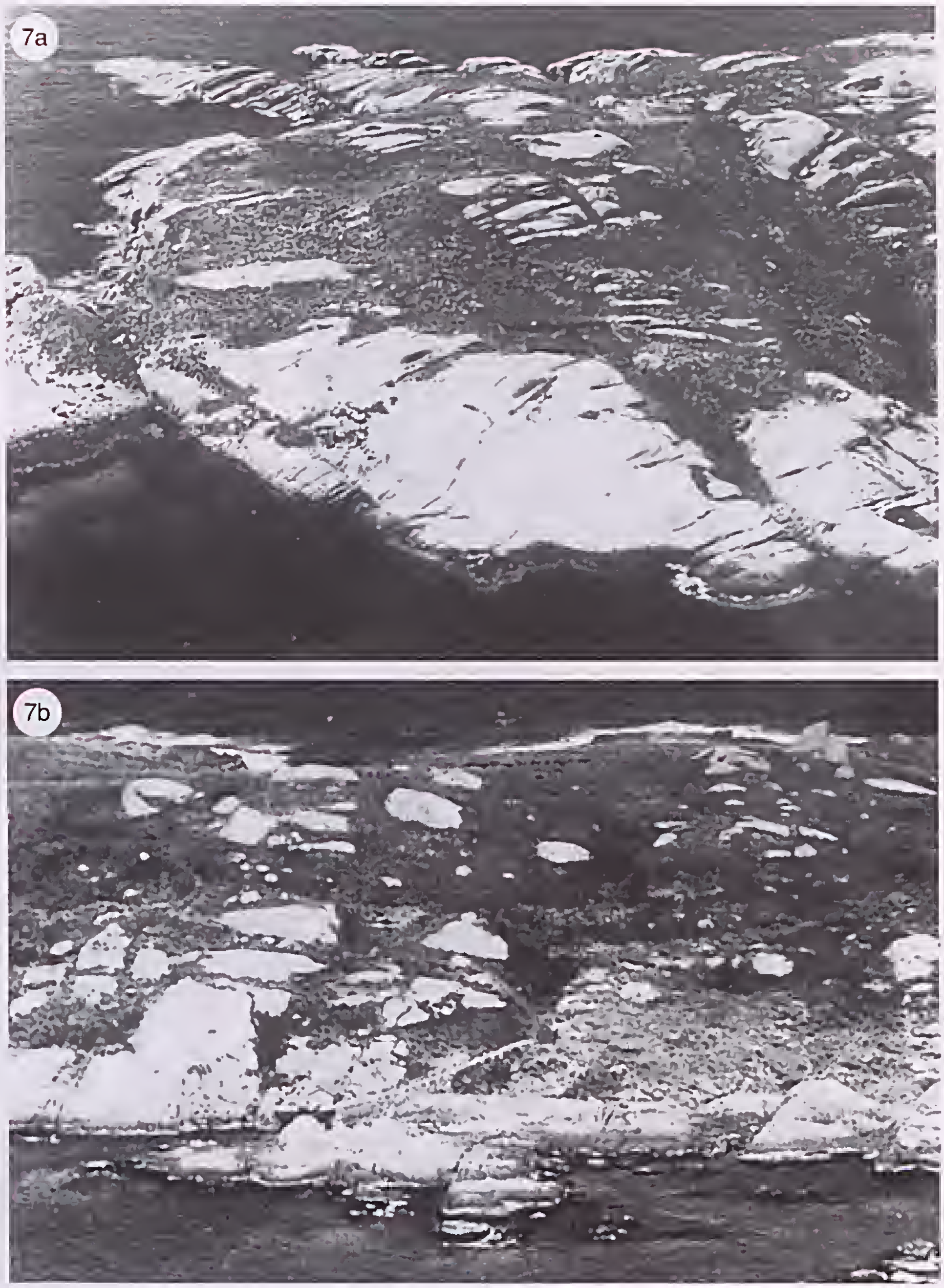


Fig. 7. Aerial views of South Island taken by Stanley Fowler on 31 October 1936.

(a) Shows the northern end of the island. The vegetation appears to be dominated by *Lomandra longifolia* interspersed with patches of lower vegetation, possibly caused by grazing. Vegetable gardens with an overgrown fence can be seen in the middle foreground, situated in a valley position with better soil moisture conditions. The gardens are now abandoned and sprawling *Dipogon lignosus*, *Acetosa sagittata* and *Pennisetum clandestinum* dominate much of the surrounding vegetation.

(b) Shows the section between the lighthouse rocks and The Twins, with the Old Jetty in the foreground. The vegetation appears to be more open than at the northern end, while in the background a band of shrubs, most likely *Breynia cernua*, can be seen. On both pictures one can barely discern the tracks leading to the lighthouse quarters, a situation very different from today with regularly mown paths, often dominated by *Pennisetum clandestinum*. (Fowler's photos A 2/72 & A2/119 reproduced with permission from CSIRO Archives.)

Beaches, deposits of shell and rock fragments, occur on flatter areas along the shore protected by rock outcrops in the tidal zone. The Gulch has the largest beach, but there are many smaller beaches especially on the less exposed west side of the island. Species typically found there are *Tetragonia tetragonioides*, *Euchylaena tomentosa*, *Einadia nutans*, *Atriplex hastata*, *Chenopodium glaucum*, *Spergularia marina* and *Sagina procumbens*, as well as introduced species which have arrived more recently along the South Coast, namely *Cakile maritima*, *Euphorbia paralias* and *Hydrocotyle bonariensis* (Heyligers 1998, 2002).

A large suite of species can be found in the wetter parts of the island, such as seepage zones at the head of coves and around rock pools. These species grow in various combinations, but it would be difficult to define plant associations due to the variability in microhabitats. A representative sample of the species found in seepage and rock pool vegetation are *Mimulus repens*, *Lobelia alata*, *Ranunculus rivularis*, *Elatine gratioloides*, *Samolus repens*, *Rumex brownii*, *Limosella australis*, *Lilaeopsis polyantha*, *Centella asiatica*, *Triglochin striata* and *Cotula coronopifolia*, as well as *Paspalum dilatatum*, *Sporobolus virginicus*, *Zoysia macrantha* and several Cyperaceae and Juncaceae. A large patch of the liverwort *Marchantia berteroana* was found in one of the seepages and the fern *Histiopteris incisa* is dominant in some gully heads. An interesting community of small herbs, notably *Hydrocotyle hirta*, *Portulacca oleracea*, *Chenopodium murale* and *Cotula australis* occurred in the

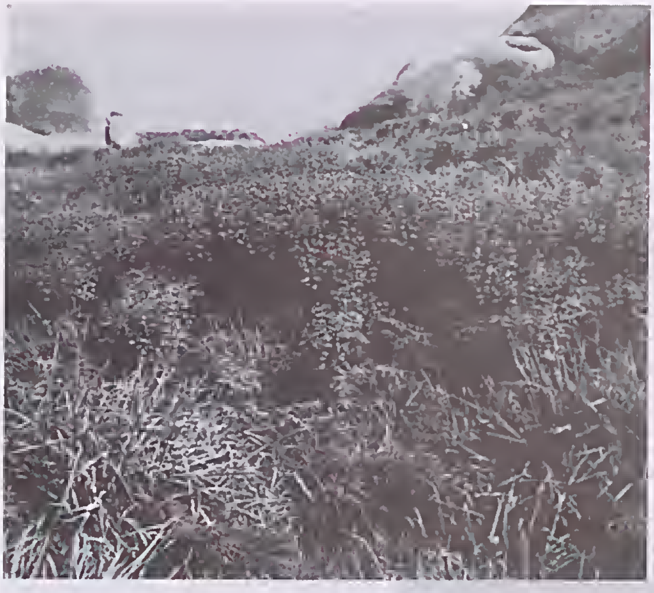
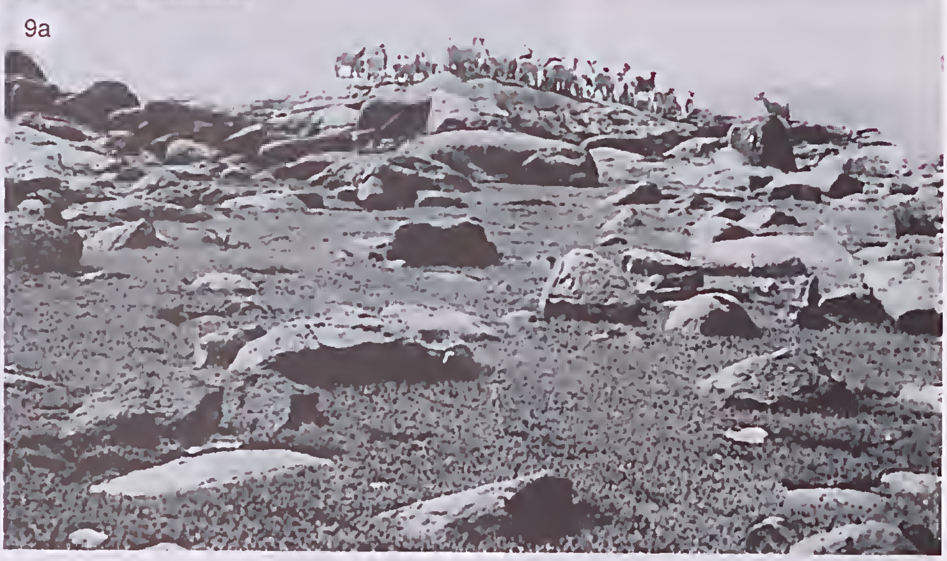


Fig. 8. A recent view of *Breynia cernua* patches growing south of the lighthouse rocks

9a



9b

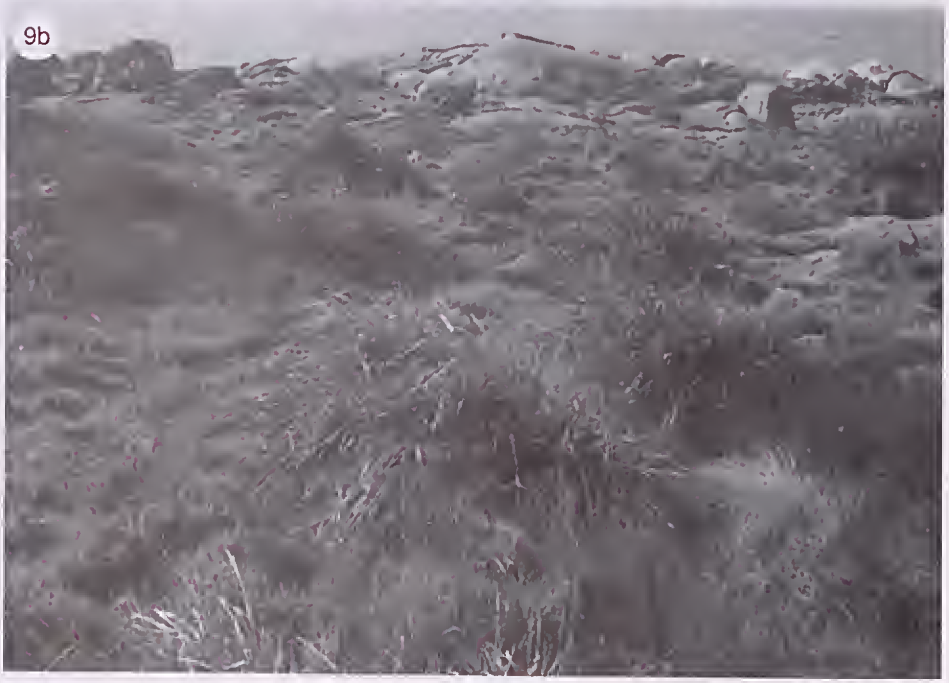


Fig. 9. (a) Goats used to shelter from northwesterly winds at the lee side of South Island. In the top picture, taken in 1959, the rock outcrops appear to be surrounded by *Zoysia – Sporobolus* vegetation. (Picture courtesy Dr A.B. Costin.)

(b) When this site was rephotographed in April 1991 many rock outcrops were partly or completely hidden in *Lomandra longifolia*, *Zoysia macrantha* and *Pennisetum clandestinum*; hence, the picture had to be taken from an elevated position to show at least some of the outcrops.

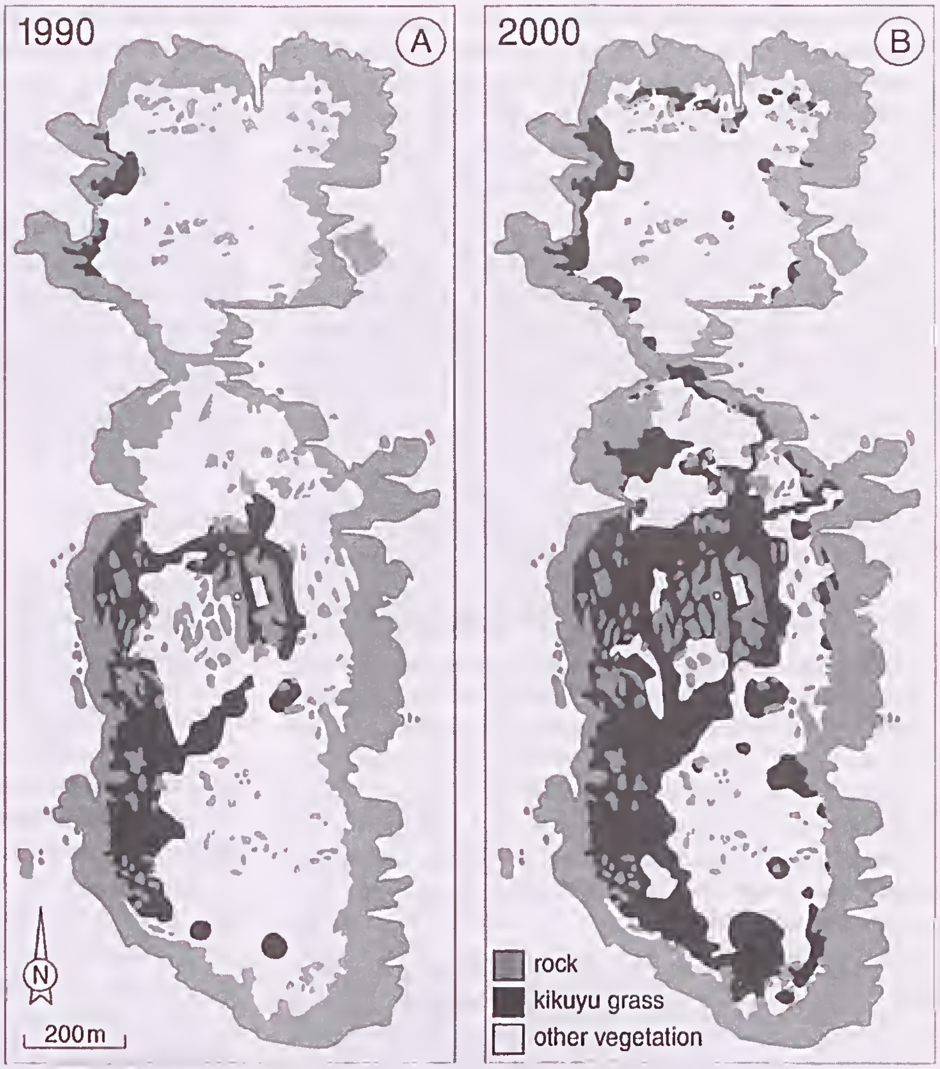


Fig. 10. Maps showing the spread of *Pennisetum clandestinum* on Montagu Island between (A) 1990 and (B) 2000, in which period the area covered by kikuyu grass increased from 16% to 37% (Weerheim et al. 2003, reproduced with permission of CSIRO Publishing).

area with *Phragmites australis* on the lower section of the track to the southern end of the island. It is no longer there, as it became overgrown by a dense low mat of regularly mown *Pennisetum clandestinum*.

Sections of cliff faces inaccessible to goats provided a refuge for several shrubs, namely *Westringia fruticosa*, *Correa alba*, *Rhagodia candolleana* and a few *Alyxia buxifolia*. Two shrubs of *Acacia longifolia* var. *sophorae* were the only woody plants that occurred away from the cliffs. *Westringia fruticosa* and *Rhagodia candolleana* bushes that were in reach of the goats have recovered and are now slowly spreading onto the upper slopes, while *Acacia longifolia* became established in at least one other site. *Pelargonium australe* is rare on Montagu Island; its occurrences are restricted to cliffs of North Island. The fern *Asplenium obtusatum* is common in crevices between, and sheltered by, taller rock outcrops around the periphery of the island.

Lichens usually cover exposed rock surfaces. Those on the rocks along the periphery show the grey, orange and yellow banding characteristic of seashores. A community of several species covers rocks further inland and, especially on southerly aspects, its growth can be luxuriant. If occurring on a steep face and after being saturated by heavy rain, the lichen cover may give way and accumulate at the foot of the outcrop. Few collections of lichens have been made and none have as yet been identified.

The role of fire

Higgins (1990) mentions that 'the 1917 lightkeepers' instructions emphasized the danger of fire and instructed keepers to burn off around the stations.' Logbooks show that this was carried out on at least six occasions, with the last recorded burn-off in 1962. It is possible that fire was more frequently lit, as there are some large gaps between the dates, especially for the early years. It remains an open question how important fire has been in shaping the vegetation. A visitor to the island in the 1930s 'walked up to the lighthouse through low shrubby heath which must have recently been on fire and where we saw many dead penguins' (B. Ferguson, quoted in Pacey 2001). A large fire on 21 December 1953, caused by embers from bushfires on the mainland, burnt most of the vegetation of South Island and killed the last specimens of *Monotoca elliptica*: a small mature tree and 'a promising seedling' (Pacey 2001). *Lomandra longifolia* and *Pteridium esculentum* both resprout after (Benson & McDougall 1993). We witnessed this after a lightning strike hit North Island in December 1991 and set fire to an area of about 150 square metres of *Lomandra–Pteridium* vegetation. The effects of this fire were still visible in March 1992, but a year later had disappeared.

In 2001 a fire that escaped from a small burn-off around the well above the cove near the old gardens, went through a large area with *Lomandra–Pteridium* and *Pennisetum* vegetation on the central west side of South Island (C.J. Tiller, pers.comm.). Observations in March 2003 showed that *Conyza* sp. had sprang up all over the burnt area. *Solanum chenopodioides* and *Tetragonia tetragonioides* were almost as abundant, while *Lomandra longifolia, Pteridium esculentum, Pennisetum clandestinum* and *Acetosa sagittata* were regenerating from charred stumps or underground parts.

The past and present flora of Montagu Island

218 vascular plants have been recorded for Montagu Island. Appendix 1 shows four groups (189 taxa), subdivided by whether they are native or naturalised and whether or not they were still present in the late 1990s i.e. about ten years after the island was declared a Nature Reserve. The fifth group brings together the 29 taxa known to have been introduced for horticultural reasons. Undoubtedly, other vegetables and garden plants will have been cultivated as well, but have remained unrecorded.

Geographic distributions of native and naturalised species have been categorised according to three criteria: native or naturalised, restricted to coastal districts or extending inland, and range size starting with the smallest (Table 1).

Native taxa

Ten species of ferns have been recorded for the island. *Pellea falcata* is only known from one location and *Cyathea australis* from two sites. Normally associated with forests, they represent relicts from a vegetation that has now disappeared. *Asplenium obtusatum* is characteristically found in crevices among the rocks around the periphery of the island. With their tough, leathery leaves the plants appear to be little affected by salt spray. It is known to hybridize with other *Asplenium* species (Walsh & Entwisle 1994) and in one location on Montagu Island a plant identified as a hybrid between *Asplenium obtusatum* and *Asplenium australasicum* (J. Croft pers. comm.) occurs next to one of *Asplenium obtusatum*. *Cheilanthes sieberi* was collected by Rodway in 1932. It may still be present on the island, as in habit it closely resembles *Cheilanthes austrotenuifolia* and may have been overlooked by other botanists.

Few surprises have turned up among the 120 native flowering plants as most of them have a wide distribution, at least in southern Australia (Table 1). *Isotoma axillaris*, when flowering, is an eye-catching species quite widespread through the more open aspects of the various *Lomandra*-dominated

Table 1. Statistical and geographic summary for the native and naturalised vascular flora of Montagu Island.

Filicopsida: Ferns, 10 species and 1 hybrid (all native).
Magnoliopsida: Flowering Plants: 178 species (109 native).
Magnoliidae: Dicotyledons, 120 species (70 native).
Liliidae: Monocotyledons: 58 species (39 native).

Geographic ranges have been coded with a capital letter and a number. C stands for coastal, in the sense that in New South Wales the species is confined to one or more of the coastal ecogeographic regions of that State (see map in Harden 1990–1993), N for: not only coastal, but also occurring in one or more of the inland ecogeographic regions.

The numbers indicate geographic ranges. For native species the numbers following C and N have different meanings, but for introduced species their meaning is the same. The numbers following the code specify the overall number of species recorded for the island and, in parentheses, the number of species still present at the end of the 1990s.

Native taxa 120 (95)

Coastal taxa 21 (18)

C 1: hybrid, restricted to Montagu Island, 1 (1)
C 2: species restricted to NSW, 1 (1)
C 3: species reaching its southern limit on Montagu Island, also occurring in Queensland, 1 (0)
C 4: species of the east coast, including East Gippsland, 2 (1)
C 5: species of southern NSW and southeastern coasts, 5 (5)
C 6: species of NSW and southern coasts, 5 (5)
C 7: widespread species, 4 also found outside Australia, 6 (5)

Species not restricted to coastal districts 99 (77)

N 1: species found in southeast Australia, 3 (3)
N 2: species found in southern Australia, 2 also in NZ, 4 (2)
N 3: species found in NSW and Queensland, 10 (8)
N 4: species found in NSW and southern States, some extending to the Pacific, 10 (7)
N 5: eastern Australian species, some not in Tasmania, 14 (12)
N 6: species extending to South Australia, 10 (6)
N 7: species in all States, some not in Northern Territory, 14 (9)
N 8: species widespread in Australia, also in New Zealand or further into the Pacific, some to America, 18 (14)
N 9: species with more extensive overseas links, usually to several continents, 16 (16)

Naturalised species 69 (39)

Coastal species 8 (6)

C 10: species occurring in both the Old and New World, 1 (1)
C 11: species only occurring in America, 3 (1)
C 12: European species, 1 (1)
C 15: Asian-African species, 1 (1)
C 17: African species, 2 (2)

Species also found inland 61 (33)

N 10: species occurring in both the Old and New World, 19 (12)
N 11: species only occurring in America, 14 (6)
N 12: European species, some also in New Zealand, 16 (10)
N 13: Eurasian species, 6 (1)
N 14: European-African species, 1 (0)
N 15: Asian-African species, 2 (2)
N 16: Asian species, 1 (1)
N 17: African species, 2 (1)

vegetation types. *Einadia hastata*, growing as compact, low bushes with dark green foliage, is also found in these vegetation types. However, the *Lomandra*- and *Pteridium*-dominated vegetation types are relatively poor in species. The variety of restricted, specialised habitats makes a much larger contribution to the species diversity of the island (Appendix 1).

Twenty-five species have either disappeared since the early 1920s or have become so rare that their presence has not been apparent (Appendix 1). Notable among the first group are *Banksia integrifolia*, *Monotoca elliptica* and *Leucopogon parviflorus*, while the latter comprises several grasses, for instance *Dichelachne crinita* and *Eragrostis elongata*. These may have disappeared due to more intensive track maintenance.

Naturalised species

Sixty nine naturalised species, naturalised in Australia, have been collected, or reported from, Montagu Island. Only a few of these are typically coastal in their distribution (Appendix 1). Most foreign species reached the island accidentally, for instance on clothing, in contaminated seed, with fodder or through seabirds. Species with buoyant propagules or wind-dispersed seeds could have arrived independently. *Stenotaphrum secundatum* was introduced for a utilitarian purpose, namely to stabilise the sand around the quarters. It is possible that some other species listed in Appendix 1 under this category, namely *Anredera cordifolia*, *Dipogon lignosus*, *Delairea odorata*, *Ipomoea cairica* and *Nothoscordum borbonicum* were introduced as garden plants, but there is no explicit evidence for this.

The occurrence of several species has been transient, as 15 were not among the collections made in the late 1980s. Since the change-over from 'homesteading' by lightkeepers to management as a Nature Reserve another 14 species have disappeared, due partly to demolition of the chicken yards and partly to more intensive track maintenance concomitant with the spread of *Pennisetum clandestinum*.

Pennisetum clandestinum is one of the naturalised species that has become a problem on the island. It smothers the vegetation into which it spreads and there is evidence that when over time it increases in volume, the area thus covered becomes unsuitable as nesting habitat for penguins (Trezise 1999, Weerheim et al. 2003). So far, the shearwater colonies are still largely free of *Pennisetum clandestinum* and no deterioration of breeding conditions has as yet been detected (Fullagar & Heyligers pers. comm. 2003). The species was introduced into Australia from the Belgian Congo and grown from seed at the Botanic Garden in Sydney in 1919. During the early 1920s it was promoted as an excellent fodder plant (Whittet 1921) and later in the same decade was introduced to the South Coast by a member of the Bates family, who returned with cuttings from the Sydney Agricultural Show (N. Hoyer, pers. comm. May 1992). How it reached Montagu Island is not known, but maybe it was carried across by courting silver gulls (G. F. van Tets pers. comm. 1988).

Unfortunately, *Pennisetum clandestinum* is not the only species that is enlarging its territory. *Acetosa sagittata*, *Dipogon lignosus* and to a lesser degree, *Delairea odorata* and *Ipomoea cairica* are in the same league. In 1988 *Acetosa sagittata* occurred over a moderately large area of mainly *Lomandra–Pteridium* vegetation to the west and south-west side of the lighthouse rocks. Its wind-dispersed fruits established new foci for spread, often at the foot of rock outcrops, especially on South Island, were it is now widespread. While the stems scramble through the vegetation, the roots form woody tubers, which can grow into the size of footballs and give the species the capacity to resprout after high intensity fires (Benson & McDougall 1999). *Dipogon lignosus*, which in 1988 grew only in a few spots on the north-west side of South Island, has rapidly expanded and now covers a substantial area at that side of the island. Together with *Pennisetum clandestinum* it hides most of the abandoned gardens and their fences. The occurrences of *Delairea odorata* are scattered throughout South Island. Its presence in various *Lomandra* and *Pteridium* vegetation types was never obvious until June 1999, when the species was profusely flowering and the many patches stood out from the rest of the vegetation. Benson & McDougall (1993) mention that in 1891 it was reported as 'a major weed carpeting the ground and covering shrubs on Gooseberry Island' in Lake Illawarra. 'Recommended control was to use goats' (sic). *Ipomoea cairica* with its showy flowers is mainly found on the rocks and in the vegetation along the track from the new jetty to the lighthouse. It is present in only a few other areas e.g. on the cliff margin of one of the coves at the east side of North Island. *Ipomoea cairica* is reported to be 'a prolific seeder and germinator' and to resprout from the base after high intensity fire (Benson & McDougall 1995). *Anredera cordifolia*, which presents problems elsewhere along the coast of New South Wales, is only known from two small patches on South Island, one of which is decreasing rather than increasing in size.

Horticultural introductions

The lightkeepers established vegetable gardens where groundwater was easily accessible. These were generally surrounded by screens to protect the plants from the salt-laden winds as well as from goats and rabbits. Rodway's list of 1932 includes vegetables as well as ornamentals (Appendix 1). Ornamentals and some vegetables were also grown in the courtyards of the living quarters (Pacey 2001). The *Pelagonium* hybrids, growing at a few spots near the quarters, would be survivors from discarded plants, but *Gladiolus* hybrids, still present in the early 1990s, have now disappeared.

Attempts in 1943 to introduce ornamental trees and shrubs were unsuccessful, but the planting in the early 1960s of New Zealand Christmas bush, *Metrosideros excelsa*, in the yard between the quarters fared better (Higgins 1990). They are now 4 m tall and, together with some other specimens in the relatively sheltered space between the quarters and the lighthouse, provide protection for vagrant or migrating Passerines (e.g. Fullagar et al. 2003, Heyligers et al. 2002). Christmas bush seeds that lodged in rock crevices have produced small wind-shorn plants, others, landing in more favourable situations, some substantial shrubs. Early in the 1980s the last lightkeeper planted a couple of *Melaleuca armillaris* shrubs at the east side of the quarters, which have grown only slowly and are still less than 2 m tall.

Few horticultural species can still be found today. Apart from the pelargoniums, there is still a wind-shorn, but fruit-bearing fig 'shrub' tucked away in a rock hollow near the quarters, and a banana plant, vegetative and only 2 m tall, survives in one of the former gardens on the north-west side of South Island. A miserable little stonefruit 'tree' and a very gnarled remnant of *Coprosma repens* are still present near where the chicken sheds used to be.

Conclusion

We would like to conclude with some thoughts on possible future changes. There is evidence that *Pennisetum clandestinum* adversely affects the breeding possibilities for penguins (Trezise 1999) and it cannot be ruled out that in the future this may happen for shearwaters too. Thus far, few areas of their colonies have been invaded by *Pennisetum clandestinum* or *Acetosa sagittata*, but over the last decade both species have markedly increased their presence in one of the sites monitored for shearwater breeding success. Montagu Island is especially important for shearwaters, as it is the only island in Australia where three species breed in mixed colonies. Management, in our view, should be directed towards maintaining suitable breeding habitat.

One of the first measures taken by the NSW National Parks and Wildlife Service after Montagu Island was declared a Nature Reserve in December 1987, was to eradicate the mob of about 60 feral goats. Goats, which had been on the island for more than a century, sometimes in more than twice the numbers present in the mid-1980s, were regarded inappropriate in a Nature Reserve (Pacey 2001). It soon became apparent that the goats had had a profound effect on the vegetation (Fig. 9). Not only were there noticeable changes in the native vegetation e.g. the expansion of creepers such as *Kennedia rubicunda* and the recovery of shrubs which had survived on largely inaccessible cliffs, but several naturalised plant species, notorious for invading existing vegetation, began to spread. Foremost among these was *Pennisetum clandestinum*, which now covers more than one-third of the island (Fig. 10). *Acetosa sagittata* is a close second, followed by *Dipogon lignosus* and *Delairea odorata*. Attempts to stem the spread of *Pennisetum clandestinum* through herbicide application were not successful as *P. clandestinum* soon bounced back. It also became apparent that rabbits, which suffer periodic outbreaks of myxomatosis, had no effect on the spread of *Pennisetum clandestinum*, as they prefer to graze the closely cropped grass on the paths. In 2000 experiments were set up by researchers from Charles Sturt University to find ways to suppress *Pennisetum clandestinum* and replace it with appropriate native woody and herbaceous species (N. I. Klomp, pers. comm.). Other invading species have been given little attention.

The accidental fire that burned a large area on the central west side of South Island in 2001, provided an opportunity for an additional experiment. In March 2002 the burnt area was planted with *Acacia longifolia* var. *sophorae*, *Banksia integrifolia*, *Westringia fruticosa* and *Lomandra longifolia*, all except *Banksia integrifolia* grown from local stock and also used in the plots of the Charles Sturt University experiment (C. J. Tiller pers. comm. 2003). In this area re-growing *Pennisetum clandestinum* is kept under control through spot application of a herbicide, but as at March 2003 no attention had been paid to *Acetosa sagittata*.

We are of the opinion that before long *Acetosa sagittata* will present problems of the same magnitude as *Pennisetum clandestinum*. The areas were *Dipogon lignosus* and *Delairea odorata* occur are still relatively small, but these species will no doubt present similar problems in the future if no immediate efforts at eradication are made.

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References

Anon. (1883) Plan of Montague Island showing position of lighthouse, quarters etc. Drawing no. 13-146H, dated 19 April 1883 (Held at Australian Archives, New South Wales branch, Sydney).

Anon. (1988) Climatic Averages Australia: Meteorological Summary 1988. Bureau of Meteorology (Australian Government Printer, Melbourne).

Austin, M.P. & Sheaffe, J. (1976) Vegetation survey data of the South Coast study area, N.S.W. Technical Memorandum 76/15, July 1976. CSIRO Division of Land Use Research, Canberra.

Basset Hull, A.F. (1908) The Montague Island gullery. *Emu* 8: 80–85.

Basset Hull, A.F. (1914) Bird Sanctuaries. *Australian Zoologist* 1(1): 13–14.

Benson, D. & McDougall, L. (1993) Ecology of Sydney plant species 1. *Cunninghamia* 3 (2): 257–422.

Benson, D. & McDougall, L. (1995) Ecology of Sydney plant species 3. *Cunninghamia* 4 (2): 217–424.

Benson, D. & McDougall, L. (1999) Ecology of Sydney plant species 7a. *Cunninghamia* 6 (2): 402–509.

Brown, I.A. (1930) The geology of the South Coast of New South Wales Part iii The monzonitic complex of the Mount Dromedary district. *Proceedings of the Linnean Society of NSW* LV: 637–697.

Crooks, J.A. & Soulé, M.E. (1999) Lag times in population explosions of invasive species: causes and complications. Pp. 103–125 in: O.T Sandlund, P.J. Schei & Å. Viken (Eds.) Invasive Species and Biodiversity Management (Kluwer Academic Publishers, Dordrecht).

Flinders, M. (1814) A Voyage to Terra Australis (G. & W. Nicol, London).

Fullagar, P.J. (1973) Seabird Islands No. 2: Montagu Island, New South Wales. *Australian Bird Bander* 11: 36–39.

Fullagar, P.J. & Heyligers, P.C. (1992) Montagu Island Penguin Census, November 1992. M I Partners Report No. 1, December 1992.

Fullagar, P.J., Davey, C.C., van Tets, G.F. & Heyligers, P.C. (1991) Is the short-tailed shearwater colonizing New South Wales? A long-term study on Montagu Island. *Nature in Eurobodalla* 5: 51–56.

Fullagar, P.J., Perkins, H.D. & Tiller, C.J. (2003) 43rd annual assessment of shearwater breeding success on Montagu Island, 26 March–1 April 2002. *Nature in Eurobodalla* 16: 60–67.

Gilham, M.E. (1960) Destruction of indigenous heath vegetation in Victorian seabird colonies. *Australian Journal of Botany* 8: 277–317.

Gilham, M.E. (1961) Plants and seabirds of granite islands in south-east Victoria. *Proceedings of the Royal Society of Victoria* n.s. 73: 21–35.

Gunn, R.H. (1978) Soils. Pp. 27–43 in: M.P. Austin & K.D. Cocks (Eds.) Land Use on the South Coast of New South Wales Vol 2: Bio-physical background studies (CSIRO, Melbourne).

Harden, G.J. (Ed.) (1990–1993) Flora of New South Wales Vols 1–4 (New South Wales University Press, Kensington).

Heyligers, P.C. (1993) A vegetation map of Montagu Island, 1990. *Nature in Eurobodalla* 7: 65–69.

Heyligers, P.C. (1998) Some New South Wales coastal plant distributions: a comparison of herbarium records with transect survey data. *Cunninghamia* 5 (3): 645–664.

Heyligers, P.C. (2002) The spread of the introduced *Euphorbia paralias* (Euphorbiaceae) along the mainland coast of southeastern Australia. *Cunninghamia* 7 (3): 101–106.

Heyligers, P.C. & Adams L.G. (1989) Vascular flora of Montagu Island, New South Wales. *Nature in Eurobodalla* 2: 36–40.

Heyligers, P.C., Perkins, H.D. & Tiller, C.J. (2002) 42nd annual assessment of shearwater breeding success on Montagu Island, 26–30 March 2001. *Nature in Eurobodalla* 15: 66–72.

Jacobs, S.W.L. & Pickard, J. (1981) Plants of New South Wales: a census of the cycads, conifers and angiosperms (Royal Botanic Gardens, Sydney).

Higgins, M. (1990) *Montague Island Lightstation; Stage 2 and Stage 3 Reports*. 12 and 4 pp. Unpublished reports to the New South Wales National Parks and Wildlife Service.

Kalma, J.D. & McAlpine, J.R. (1978) Climate. Pp.1–15 in: M.P. Austin & K.D. Cocks (Eds.) Land Use on the South Coast of New South Wales Vol 2: Bio-physical background studies (CSIRO: Melbourne).

Pacey, L. (1991) *The Lure of Montague*. 34 pp. (Narooma, published by the author.)

Pacey, L. (2001) *The Lure of Montague*. Revised edition, 72 pp. (Narooma, published by the author.)

Reed, A.W. (1969) Place-names of New South Wales, their origins and meanings (Reed, Sydney).

Rippey, E., Rippey, J.J., Green, B. & Dunlop, J.N. (2002) Comparison of the vegetation of the islands in Shoalwater Bay (Rockingham, Western Australia) with that of the coastal bushland. *Journal of the Royal Society of Western Australia* 85: 169–179.

Rodway, F.A. (1932) The vegetation of Montague Island. *The Australian Naturalist* 8 (7): 143.

Trezise, N.R. (1999) The breeding population of Little Penguins (*Endyptula minor*) on Montague Island, New South Wales, 1992–1998. B.Sc.(Hon.) Thesis, Charles Sturt University, Albury.

Walsh, D., Kirkpatick, J.B. & Skira, I.J. (1997) Vegetation patterns, environmental correlates and vegetation change in a *Puffinus tenuirostris* breeding colony at Cape Queen Elizabeth, Tasmania. *Australian Journal of Botany* 45: 71–79.

Walsh, N.G. & Entwisle, T.J. (Eds.) (1994–1999) Flora of Victoria Vols 2–4 (Inkata Press, Melbourne).

Weerheim, M.S., Klomp, N.I., Brunsting, A.M.H. & Komdeur, J. (2003) Population size, breeding habitat and nest site distribution of little penguins (*Eudyptula minor*) on Montague Island, New South Wales; implications for conservation. *Wildlife Research* 30: 1–7.

Whittet, J.N. (1921) A promising introduction. Kikuyu Grass (*Pennisetum longistylum* (Hochst)). *Agricultural Gazette of New South Wales* 32: 313–322.

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Appendix 1: Inventory of the vascular plants of Montagu Island, New South Wales

Families, genera and species are listed alphabetically in four groups, based on whether they are native or naturalised and whether they were still present or not in the late 1990s. Species that were used in horticulture are listed as a fifth group.

Each species has a code indicating its geographic range. These codes are defined in Table 1.

Abundance refers to how common a species is in a particular habitat or vegetation type. If the species occurs in a variety of situations, its occurrence has been indicated as widespread. The following abbreviations have been used:

v co: very common; co: common; ra co: rather common; unco: uncommon; loc co: locally common (found in good numbers where it occurs); loc: localised (only a few individuals or small patches); occ: occasional (unpredictable in occurrence); rare: rare in specified vegetation type or habitat; gone: extinct on Montagu Island; gone?: not seen recently, likely to be extinct.

Lomandra vegetation encompasses the various vegetation types in which *L. longifolia* is dominant or codominant. *Zoysia–Sporobolas* vegetation is the revised name of the *Zoysia–Poa* vegetation type (see Fig. 1).

The last column documents whether the species is represented by a collection (capital letter of collectors name) or was only seen (lower case letter). Names, year or years of collecting, and the herbarium where the specimen or, in the case of duplicate collections, the primary specimen is located are as follows:

A,a: L.G. Adams, 1973, CANB; Ca: J. Cassell, 1949, 1964, NSW; Co: A.B. Costin, 1959, NSW; F: L. Fraser, 1935, NSW; H, h: P.C. Heyligers, 1988–2003, CANB, but Carpobrotus collections are at AD; J: L.A.S. Johnson, 1950, NSW; M: A. Melvaine, 1935, NSW; R, r: F.A. Rodway, 1921 (collected by W.H. Williams, lightkeeper), 1932, NSW; S: H. Schröter, 1935, NSW; W: A. Warner, 1958, CANB.

Floristic list

	Geog.	Abund.	Comments	Collectors
Native species (95) and one hybrid still present				
Aizoaceae				
Tetragonia tetragonioides	N 9	co	Upper beaches, also opportunistic, e.g. tracks	R A H
Amaranthaceae				
Alternanthera denticulata	N 7	rare	Opportunistic, a favoured rabbit food	R a H
Apiaceae				
Apium prostratum var. *filiforme*	N 8	ra co	Moist areas	a H
Centella asiatica	N 9	ra co	Moist areas	H
Hydrocotyle hirta	N 7	unco	Moist areas around periphery	H
Lilaeopsis polyantha	N 4	rare	Around rock pools	H
Apocynaceae				
Alyxia buxifolia	C 5	rare	Cliff faces and margins	H
Parsonsia straminea	N 3	loc co	Northwest facing slope of South Island	H
Asclepidiaceae				
Marsdenia rostrata	N 5	co	Throughout *Lomandra* vegetation	R W H
Aspleniaceae				
Asplenium flabellifolium	N 8	co	Shaded cliffs and steep slopes	A H
Asplenium obtusatum	C 5	ra co	Crevices in rock outcrops of the periphery	R M Ca H
A. obtusatum × *A. australasicum*	C 1	rare	In crevice next to an *A. obtusatum* plant	H
Asteraceae				
Centipeda minima subsp. *minima*	N 5	unco	Seepage areas over rock outcrops	A H
Cotula australis	N 7	unco	Shallow sandy areas, usually moist	A H
Cotula coronopifolia	N 7	loc	Around and in rock pools	R a H
Ozothamnus diosmifolius	N 3	rare	Shallow soil near crest of North Island	H
Pseudognaphalium luteo-album	N 9	occ	Tracks and open vegetation	R W a H
Senecio minimus	N 4	rare	In steep alcove head	H
Callitrichaceae				
Callitriche sonderi	N 7	unco	Around rock pools	A H
Campanulaceae				
Wahlenbergia gracilis	N 5	unco	Tracks and open vegetation	R H
Wahlenbergia stricta	N 5	unco	Tracks and open vegetation	R H
Caryophyllaceae				
Spergularia marina	C7	unco	Beaches, damp sites in *Zoysia–Sporobolus* veg.	A H
Centrolepidae.				
Centrolepis strigosa	N 8	loc	Sandy area between rock outcrops on South Is.	A
Chenopodiaceae				
Atriplex australasica	C 5	ra co	Beaches	A H
Chenopodium glaucum	N 4	occ	Beaches	A
Einadia hastata	N 5	ra co	Open *Lomandra*, and other vegetation	a H
Einadia nutans subsp. *nutans*	N 6	unco	Moist areas e.g. sheltered cliff faces	R F A H
Einadia trigonos subsp. *trigonos*	N 1	unco	Moist areas e.g. sheltered cliff faces	Co A H
Enchylaena tomentosa	N 4	ra co	Beaches	R F J a H
Rhagodia candolleana subsp. *candolleana*	C 6	co	Cliff faces, margins and lower slopes	A H

Commelinaceae				
Commelina cyanea	N 3	co	Widespread	R A H
Convolvulaceae				
Dichondra repens	N 8	rare	Moist situations	R a H
Crassulaceae				
Crassula peduncularis	N 1	rare	Damp sandy soil overlying granite	A
Crassula sieberiana	N 8	co	Crevices in rock outcrops	R H
Cyatheaceae				
Cyathea australis	N 5	rare	South-facing slope on North Is, crevice on South Is.	a H
Cyperaceae				
Carex appressa	N 8	unco	Margins of rock pools	a H
Cyperus brevifolius	N 9	ra co	Moist areas	H
Cyperus gracilis	N 3	rare	Seepage areas	a H
Isolepis cernua	N 9	co	Margins of rock pools	a H
Isolepis inundata	N 9	loc	Seepage areas along cliffs	H
Isolepis nodosa	C 7	v co	Widespread *Lomandra*, and mixed grasses veg.	R A H
Lipocarpha microcephala	N 8	loc	Moist area in *Stenotaphrum* sward near quarters	H
Pycreus polystachyos	N 9	loc	Moist areas, mainly near rock pools	R A H
Dennstaedtiaceae				
Histiopteris incisa	N 9	loc co	Moist areas in alcove heads	A H
Hypolepis amaurorachis	C 5	rare	In *Phragmites australis* vegetation	H
Pteridium esculentum	N 8	v co	A major element of the vegetation	R a H
Dicksoniaceae				
Calochlaena dubia	N 5	rare	Rock crevices in crestal area of North Island	H
Elatinaceae				
Elatine gratioloides	N 6	ra co	Rock pools	A H
Euphorbiaceae				
Breynia cernua	N 3	loc co	Scrub patches in *Lomandra* vegetation	A H
Fabaceae				
Acacia longifolia var. *sophorae*	C 7	rare	Wide rock crevices, road cutting on South Island	r H
Glycine microphylla	N 6	rare	*Lomandra* vegetation	H
Kennedia rubicunda	N 5	co	*Lomandra*, and rank Pennisetum vegetation	b R a H
Geraniaceae				
Pelargonium australe	N 7	rare	Cliff ledges on North Island	R a H
Hypoxidaceae				
Hypoxis hygrometrica	N 5	loc	Periodically wet sandy patches on flat rocks	R a H
Juncaceae				
Juncus bufonius	N 9	unco	Moist areas in *Zoysia–Sporobolus* vegetation	a H
Juncus pallidus	N 4	rare	Lomandra vegetation on North Island	H
Juncus pauciflorus	N 2	loc	Seepage area in alcove head, North Island	H.
Juncus usitatus	N 8	rare	*Poa–Lomandra* vegetation, North Island	H
Juncus vaginatus	N 6	occ	Lomandra- and Pennisetum vegetation	R H
Juncaginaceae				
Triglochin striata	C 7	occ	Moist areas around rockpools	H
Lamiaceae				
Plectranthus graveolens	N 3	ra co	Rock outcrop fringes in *Lomandra* vegetation	R a H
Westringia fruticosa	C 2	ra co	Cliff faces and rock outcrops at cliff margins	R A H
Lobeliaceae				
Isotoma axillaris	N 5	ra co	Open *Lomandra* vegetation	A H
Lobelia alata	N 8	co	Moist areas, also *Zoysia–Sporobolus* vegetation	a H
Lomandraceae				
Lomandra longifolia	N 6	v co	Widespread, often dominant or co-dominant	R a H
Menispermaceae				
Stephania japonica var. *discolor*	N 3	co	Widespread	R Ca A H
Oxalidaceae				
Oxalis corniculata	N 9	unco	Gritty rock crevices	R A H
Phormiaceae				
Dianella longifolia	N 7	rare	Mixed grasses vegetation	H
Poaceae				
Agrostis avenacea var. *avenacea*	N 8	occ	Opportunistic, beaches	A H
Austrostipa stipoides	C 5	loc	Cliff margins and scree slopes	a H
Echinopogon ovatus	N 8	occ	Opportunistic	H
Entolasia marginata	N 5	ra co	Rocky areas with mixed grasses vegetation	H
Eragrostis leptostachya	N 3	ra co	Rocky areas with mixed grasses veg., crevices	R a H

Imperata cylindrica var. *major*	N 9	ra co	Mixed grasses vegetation and other dry areas	r a H
Microlaena stipoides var. *stipoides*	N 4	ra co	Mixed grasses vegetation, tracks	a H
Phragmites australis	N 9	co	Seepages, periodically wet areas	R a H
Poa poiformis	C 6	co	A major element of the vegetation	R S W Co H
Sporobolus virginicus var. *minor*	C 7	co	Dominant in *Zoysia–Sporobolus* vegetation	H
Themeda triandra	N 7	ra co	Mixed grasses vegetation	R a H
Zoysia macrantha	C 4	co	*Zoysia–Sporobolus* and mixed grasses vegetation	a H
Polygonaceae				
Rumex brownii	N 8	unco	Moist to wet areas	R a H
Portulacaceae				
Portulaca oleracea	N 9	ra co	Moist areas; favoured rabbit food	R a H
Primulaceae				
Samolus repens	C 6	co	Near rock pools and in seepage areas	A H
Ranunculaceae				
Ranunculus amphitrichus	N 1	occ	Seepage areas	a H
Rutaceae				
Correa alba	C 6	ra co	Cliff faces	W A H
Scrophulariaceae				
Limosella australis	N 2	unco	Near rock pools	A H
Mimulus repens	C 6	ra co	Damp and wet areas	H
Veronica plebeia	N 7	rare	Rock crevices	H
Sinopteridaceae				
Cheilanthes austrotenuifolia	N 4	ra co	Crevices in 'flat' rock outcrops	A H
Pellaea falcata var. *falcata*	N 9	one site	Rocky crest with *Lomandra longifolia*	H
Solanaceae				
Solanum americanum	N 9	ra co	Widespread, open vegetation	H
Solanum prinophyllum	N 5	rare	Opportunistic, flotsam	a H
Solanum vescum	N 6	ra co	Open *Lomandra* vegetation	H
Typhaceae				
Typha cf. *domingensis*	N 9	rare	Around well and rock pools	h
Urticaceae				
Urtica incisa	N 8	ra co	In *Lomandra* vegetation	R A H
Introduced species still present (40)				
Alliaceae				
Nothoscordum borbonicum	N11	loc	Rank *Pennisetum* vegetation near lighthouse	H
Apiaceae				
Hydrocotyle bonariensis	C11	loc co	At rear of alcoves, around well	H
Asteraceae				
Conyza bonariensis	N11	occ	Opportunistic, disturbed areas	R a h
Delairea odorata	C17	ra co	In Lomandra vegetation	A H
Dittrichia graveolens	N12	occ	Sand-filled crevasses in flat rocks	H
Gamochaeta pensylvanica	C11	occ	In *Poa–Lomandra* vegetation	H
Hypochoeris radicata	N12	occ	Ruderal	a H
Sonchus asper subsp. *glaucescens*	N12	rare	Ruderal	H
Sonchus oleraceus	N12	rare	Ruderal	H
Basellaceae				
Anredera cordifolia	N11	loc	*Pennisetum* veg. at quarters and former gardens	H
Brassicaceae				
Cakile maritima subsp. *maritima*	C10	ra co	Beaches of South Island and Gulch	H
Caryophyllaceae				
Polycarpon tetraphyllum	N12	unco	Moist situations	a H
Sagina procumbens	N10	unco	Moist situations	A H
Stellaria media	N10	rare	Seepage areas in alcoves	Co a H
Chenopodiaceae				
Atriplex prostrata	N12	unco	Sandy rock crevices of periphery	H
Convolvulaceae				
Ipomoea cairica	C15	loc co	Rock outcrops, cliffs, rank *Pennisetum* veg.	a H
Cucurbitaceae				
Cucumis myriocarpus subsp. *leptodermis*	N16	occ	Ruderal, flotsam lines	A H
Euphorbiaceae				
Euphorbia paralias	C12	loc co	On two beaches, among boulders	H

Fabaceae				
Dipogon lignosus	C17	loc co	Disturbed sites at north side of South Island	H
Trifolium cernuum	N12	rare	Damp sites on shallow soil	r a H
Phytolaccaceae				
Phytolacca octandra	N11	co	Ruderal, open *Lomandra* vegetation	R a H
Poaceae				
Bromus catharticus	N10	occ	Opportunistic	a H
Cynodon dactylon	N10	unco	*Zoysia–Sporobolus* vegetation	R W a H
Digitaria ciliaris	N10	occ	Opportunistic	R a H
Eleusine indica	N10	occ	Opportunistic	H
Lagurus ovatus	N12	unco	Open areas on tracks	a H
Paspalum dilatatum	N11	occ	Opportunistic	H
Paspalum distichum	N10	ra co	Margins of rock pools	H
Pennisetum clandestinum	N15	v co	Opportunistic	H
Poa annua	N10	unco	Opportunistic	a H
Polypogon monspeliensis	N12	loc co	*Zoysia–Sporobolus* vegetation	H
Sporobolus indicus var. *capensis*	N15	unco	Ruderal, usually on tracks	R A H
Stenotaphrum secundatum	N10	ra co	*Lomandra* veg. in central area of South Island	R a H
Vulpia bromoides	N13	occ	Ruderal	a H
Vulpia myuros f. *myuros*	N10	occ	Ruderal	H
Polygonaceae				
Acetosa sagittata	N17	v co	Widespread, especially on South Island	H
Primulaceae				
Anagallis arvensis	N12	unco	Damp areas, ruderal	a H
Solanaceae Disturbed lower slopes, flotsam	a H			
Solanum chenopodioides	N11	ra co	Widespread ruderal	H
Solanum nigrum	N10	occ	Ruderal	R a H

Native species of doubtful presence or gone (25)

Aizoaceae				
Carpobrotus glaucescens	C 4	gone?	Sandy spot between rocks, cliff ledge	a H
Asclepidiaceae				
Tylophora barbata	N 4	gone		A
Asteraceae *Cymbonotus lawsonianus*	N 6	gone	Near lighthouse quarters	R
Gnaphalium involucratum	N 2	gone		a
Senecio biserratus	N 4	gone	Near lighthouse quarters	H
Senecio hispidulus	N 4	gone		a
Chenopodiaceae				
Chenopodium carinatum	N 3	gone		R a
Chenopodium pumilio	N 7	gone		R
Salsola kali	N 7	gone		A
Epacridaceae				
Leucopogon parviflorus	C 7	gone		a
Monotoca elliptica	N 5	gone		R Ca
Fabaceae				
Glycine clandestina	N 6	gone?		R a
Juncaceae				
Juncus planifolius	N 8	gone		a
Oxalidaceae				
Oxalis thompsoniae	N 6	gone		R
Plantaginaceae				
Plantago ?debilis	N 7	gone		a
Poaceae				
Elymus scaber	N 8	gone?		H
Dichelachne crinita	N 8	gone?	Opportunistic	a H
Eragrostis elongata	N 7	gone?	Opportunistic	H
Poa labillardieri	N 6	gone?	Near lighthouse	H
Sporobolus diander	C 3	gone		a
Sporobolus elongatus	N 3	gone		a
Portulacaceae				
Calandrinia eremaea	N 7	gone?	Deposition hollows and crevices on rocks	H
Proteaceae				
Banksia integrifolia	N 5	gone		r

Scrophulariaceae				
Veronica calycina	N 2	gone?	Track through dense, low *Pennisetum* vegetation	A H
Sinopteridaceae				
Cheilanthes sieberi subsp. *sieberi*	N 8	gone?	Crevices in 'flat' rock outcrops	R
Introduced species of doubtful presence or gone (29)				
Amaranthaceae				
Amaranthus viridis	N11	gone?	Ruderal, a favoured rabbit food	H
Asteraceae				
Aster subulatus	N11	gone		R a
Cirsium vulgare	N12	gone?	Ruderal	r H
Gnaphalium purpureum	N11	gone		a
Hypochoeris glabra	N13	gone		R
Soliva anthemifolia	N11	gone		a
Tagetes minuta	N11	gone		A
Taraxacum officinale	N13	gone		R a
Caryophyllaceae				
Cerastium glomeratum	N12	gone		a
Paronychia brasiliana	N11	gone		a
Chenopodiaceae				
Chenopodium album	N13	gone		a
Chenopodium murale	N10	gone?	Ruderal	R A H
Fabaceae				
Trifolium glomeratum	N12	gone		a
Trifolium repens	N13	gone		a
Juncaceae				
Juncus effusus	N12	gone		a
Malvaceae				
Malva parviflora	N12	gone		a
Modiola caroliniana	N11	gone	Opportunistic	a h
Oxalidaceae				
Oxalis debilis var. *corymbosa*	C11	gone?	Among *Pennisetum* vegetation near quarters	H
Papaveraceae				
Argemone ochroleuca subsp. *ochroleuca*	N11	gone	At abandoned chook sheds	H
Poaceae				
Aira caryophyllea	N10	gone		a
Briza minor	N10	gone?	Moist sandy depressions on rocks near quarters	H
Holcus lanatus	N10	gone	*Stenotaphrum* sward near quarters	H
Polygonaceae				
Acetosella vulgaris	N10	gone	Opportunistic	R a
Rumex crispus	N13	gone?	*Pennisetum* vegetation on runoff area	H
Rosaceae				
Rubus discolor	N12	gone?	Alcove head near New Jetty	H
Scrophulariaceae				
Verbascum virgatum	N12	gone	At abandoned chicken sheds	H
Solanaceae				
Lycium ferocissimum	N17	gone	One shrub in rock crevice, eradicated	H
Solanum sarrachoides	N10	gone?	Opportunistic, Gulch beach	H
Urticaceae				
Urtica urens	N14	gone?	Ruderal	A
Horticultural taxa (29)				
Agavaceae				
Agave americana		gone	One plant; destroyed	h
Alliaceae				
Allium porrum		gone	Few plants in abandoned garden in late 1980s	h
Amygdalaceae				
Prunus sp. cf. *persica*		loc	A small tree surviving in lee of storage shed	h
Apiaceae				
carrots		gone	Vegetable gardens (Rodway's diary)	r
Araceae				
Zantedeschia aethiopica		loc	In seepage area near abandoned garden	H

Brassicaceae			
Lobularia maritima	gone	Grew in courtyard garden	H
cabbages	gone	Vegetable gardens (Pacey 2001)	
cauliflowers	gone	Vegetable gardens (Pacey 2001)	
Cannaceae			
small cannas	gone	Vegetable gardens (Rodway's diary)	r
Chenopodiaceae			
silverbeet	gone	Vegetable gardens (Rodway's diary)	r
Convolvulaceae			
sweet potatoes	gone	Vegetable gardens (Pacey 2001)	
Cucurbitaceae			
Cucurbita pepo (marrow)	gone	Grew on former chicken-shed site	H
Fabaceae			
peas	gone	Vegetable gardens (Rodway's diary)	r
beans	gone	Vegetable gardens (Pacey 2001)	
Geraniaceae			
Pelargonium domesticum (hybrids)	loc	Two varieties, in sheltered positions near quarters	r, H
Iridaceae			
small iris	gone	Vegetable gardens (Rodway's diary)	r
Crocosmia crocosmiiflora (hybrid)	gone	Grew in seepage area near quarters	H
Gladiolus sp. (hybrids)	gone	Grew in seepage area near quarters	H
Lamiaceae			
rosemary	gone	Vegetable gardens (Rodway's diary)	r
Moraceae			
Ficus cairica	loc	Sheltered position in deep crevice near quarters	r, h
Musaceae			
Musa acuminata × *M. balbisiana*	loc	Abandoned garden in northwest of South Island	h
Myrtaceae			
Melaleuca armillaris	loc	2 shrubs planted at east side of quarters in c.1985	H
Metrosideros excelsa	loc	Several planted near quarters in the early 1960s	H
Rubiaceae			
Coprosma repens	occ	A shrub in lee of shed; few seedlings elsewhere	H
Solanaceae			
tomatoes	gone	Vegetable gardens (Rodway's diary)	r
Nicotiana tabacum	gone	A wildling on steep alcove slope on North Island	H
Physalis peruviana	gone	Vegetable gardens (Pacey 2001)	H
Solanum tuberosum	gone	Few plants in abandoned garden in late 1980s	h
Violaceae			
violets	gone	Vegetable gardens (Rodway's diary)	r

Floristic patterns along an east–west gradient in grassy box woodlands of Central New South Wales

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Abstract: Temperate grassy box woodlands are the predominant native vegetation of the 'wheat-sheep' belt of south-eastern Australia. In New South Wales, a number of different eucalypt species form the overstorey of these woodlands, with changes in dominance from *Eucalyptus melliodora* (Yellow Box) and *Eucalyptus albens* (White Box) in the east to *Eucalyptus microcarpa* (Grey Box) and *Eucalyptus populnea* (Poplar Box) in the west. Most grassy Box woodlands have now been cleared or modified for agriculture, and their conservation is dependent on adequate knowledge of the distribution, ecology and management needs of remaining woodlands. In this study we describe the understorey flora of high quality remnants of grassy Box woodlands along an east-west gradient in central New South Wales, comparing sites with a history of minimal livestock grazing (cemeteries) with sites with a history of intermittent livestock grazing (travelling stock reserves). With some important exceptions relating to *Eucalyptus melliodora*, dominant overstorey eucalypts were good indicators of understorey changes along the east-west gradient. A particular disjunction, involving changes in the dominant grasses from *Themeda australis* and *Poa sieberiana* to *Austrostipa scabra*, *Austrodanthonia* and *Enteropogon* species, distinguishes 'eastern' (*Eucalyptus melliodora*, *Eucalyptus albens*) from 'western' (*Eucalyptus microcarpa*, *Eucalyptus populnea*) Box woodlands, and has significant implications for understorey management. Notable changes in subsidiary species included changes in the main genera of shrubs and daisies, and a number of trends at the family level. Families such as Dilleniaceae, Haloragaceae, Epacridaceae and Ranunculaceae were more frequent or diverse in eastern Box woodlands, and gave way to species of the families Malvaceae, Chenopodiaceae, Myoporaceae, Amaranthaceae and Brassicaceae in the west. Intermittent grazing influenced understorey composition in all box woodlands sampled, although influences in western Box woodlands were less pronounced. Effects of grazing included a decline in shrub abundance and loss of a range of native perennials across all woodlands, changes to the dominant grasses and a considerable increase in exotic annuals in the east, and a decline in native grass diversity and increase in native annuals in the west.

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Introduction

Temperate grassy box woodlands are the predominant native vegetation of the productive soils of the 'wheat-sheep' belt of south-eastern Australia. Before European settlement, they occupied millions of hectares on the Tablelands, Slopes and Plains of New South Wales, on the Wimmera and Northern Plains of Victoria, and on the Darling Downs of southern Queensland (AUSLIG 1990a, Keith 2002).

In central NSW, a number of different eucalypt species form the overstorey of grassy box woodlands, with changes in dominance broadly reflecting rainfall and temperature gradients with distance inland. Yellow Box *(Eucalyptus melliodora)* and Red Gum *(Eucalyptus blakelyi)* are dominant on the Tablelands, and form mosaics with White Box *(Eucalyptus albens)* in the eastern Slopes regions. Grey Box *(Eucalyptus microcarpa)* and occasionally Fuzzy Box *(Eucalyptus conica)* become dominant further to the west, especially on alluvial red brown earths, and Bimble Box *(Eucalyptus populnea)* forms large tracts of woodland still further west (Beadle 1948, Moore 1953a). Black Box *(Eucalyptus largiflorens)* also forms distinct communities on heavy alluvial soils in western NSW (Beadle 1948), but these were not a subject of this study.

Grassy box woodlands are distinguished from shrub woodlands by the presence of a well-developed grass and forb layer and the lack of a dense shrub layer, although scattered or patchy shrubs may be present. Woodlands with a grassy understorey predominate on the better soils in the White Box, Yellow Box and Red Gum regions, and some of the Grey and Bimble Box regions (Moore 1953a, Moore 1993, Prober 1996). Box woodlands with a more shrubby understorey predominate in lower rainfall areas in the west, especially in the Bimble Box areas (Beadle 1948, Beeston et al. 1980, Moore 1993), and on shallower or lower nutrient soils in more eastern woodlands (Prober 1996, Keith 2002). Understorey types tend to intergrade on intermediate sites, but at the extremes the shrubby and grassy understoreys may share few species. This study focused on woodlands with a grassy understorey.

Owing to the productive nature of the soils they grow on, most of the grassy box woodlands have been cleared for agriculture, and uncleared areas have been modified to varying degrees by livestock grazing or other disturbance. As a result, grassy box woodlands have been classified as one of the most poorly conserved ecological communities in Australia (Specht 1981, Benson 1991), and some types have been listed as endangered ecological communities in NSW

(White Box, Yellow Box, Blakely's Red Gum Woodland under the *NSW Threatened Species Conservation Act* 1995), the Australian Capital Territory (Yellow Box and Red Gum Woodland under the *Nature Conservation Act 1980*) and nationally (Grassy White Box Woodlands under the *Environment Protection and Biodiversity Conservation Act* 1999). Efforts to conserve the grassy Box woodlands are increasing, and include remnant fencing programs (McDonald 2000), extension programs (Elix & Lambert 1998), coordinated protection and management of remnants through the Grassy Box Woodlands Conservation Management Network (Prober et al. 2001), and legislative controls (e.g. state vegetation clearance controls and threatened ecological community listings).

The success of such conservation efforts in the box woodlands is dependent on adequate ecological knowledge, including an understanding of environmental and management-induced patterns in floristic and faunal composition. Currently such information is patchy, and detailed information is completely lacking for some of the box woodlands and for many fauna groups. Most botanical studies of grassy box woodlands in NSW have focused on regional vegetation classification and mapping (e.g. Moore 1953a, Beadle 1948, Costin 1954, Moore 1970, Sivertsen & Metcalfe 1995, Austin et al. 2000, Keith 2002). These studies were largely based on overstorey species, but provide general descriptions of understorey composition and some include more detailed discussion of perceived changes in the understorey resulting from European settlement (Beadle 1948, Moore 1953b, Costin 1954, Moore 1970). Prober and Thiele (1995) and Prober (1996) undertook broadscale analyses of environmental and management induced variation in the understorey of grassy White Box woodlands throughout their range in NSW. However, relationships between understorey, environment and management across the different box woodland types are still poorly understood.

In this study, we sampled the understorey flora of grassy Yellow Box (*Eucalyptus melliodora*), Red Gum (*Eucalyptus blakelyi*), White Box (*Eucalyptus albens*), Grey Box (*Eucalyptus microcarpa*) and Bimble Box (*Eucalyptus populnea*) woodlands along an east–west gradient in central NSW. As these ecological communities are highly disturbed across their range, we focused on data from the least-disturbed remnants available, comparing cemetery remnants (with a history of minimal or no livestock grazing) with some of the least disturbed travelling stock routes and reserves (TSRs, with a history of intermittent livestock grazing). Our aims were to describe natural patterns in native understorey composition across the gradient, to assess relationships between understorey and overstorey composition, and to compare the effects of these two broadly differing management regimes across the range of woodland types. It was also important to begin identification of significant remnants and contribute to an improved understanding of the native understorey in Grey and Bimble Box Woodlands, where conservation efforts are particularly hindered through lack of such information.

Methods

Sampling strategy

Floristic data were collected for 82 grassy box woodland remnants across an east–west gradient in central NSW, representing a general decline in rainfall from 800 mm on the Tablelands to 400 mm on the Western Plains (AUSLIG 1990b). Sampling extended from Hall (Australian Capital Territory, 120 km inland) to Nymagee (506 km inland), with most samples concentrated within the region defined approximately by the towns Condobolin, Narrandera, Canberra and Wellington (Fig. 1). Sites were spread across a relatively broad latitudinal range and included outliers at Nymagee and Trangie (Fig. 1), in order to capture information from rare, little-disturbed cemetery remnants.

Given the rarity of high quality native understorey in the highly disturbed and fragmented grassy woodlands characteristic of this region, our sampling strategy focused on seeking out sites with relatively good-condition native understorey. Earlier studies in grassy woodlands and

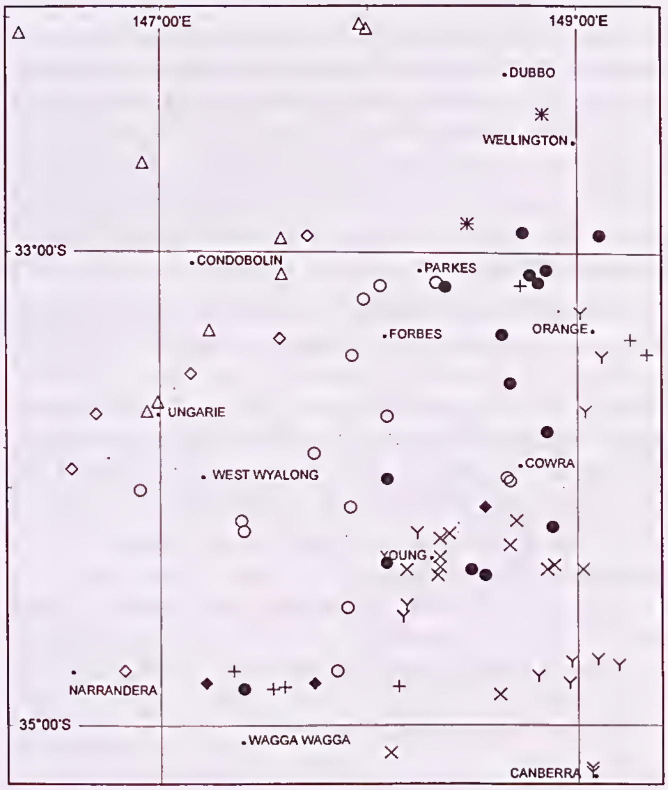

Fig. 1. Map showing the distribution of sites sampled and their dominant overstorey eucalypts:

Y *Eucalyptus melliodora* & *Eucalyptus blakelyi* (Yellow Box, Red Gum)
+ *Eucalyptus melliodora* (Yellow Box)
× *Eucalyptus albens* & *Eucalyptus melliodora* (White Box, Grey Box)
● *Eucalyptus albens* (White Box)
◆ *Eucalyptus albens* & *Eucalyptus microcarpa* (White Box, Grey Box)
○ *Eucalyptus microcarpa* (Grey Box)
◇ *Eucalyptus microcarpa* & *Eucalyptus populnea* (Grey Box, Bimble Box)
△ *Eucalyptus populnea* (Bimble Box)
✳ *Eucalyptus conica* (Fuzzy Box)

grasslands have shown that little-used country cemeteries, roadsides and TSRs are important refugia for woodland and grassland flora (Stuwe & Parsons 1977, Prober & Thiele 1995), thus site selection was restricted to remnants in either cemeteries (with a history of minimal grazing by livestock), or TSRs and roadsides, which generally have a history of intermittent livestock grazing.

Selection of sample sites within the two landuse classes was subjective, as high quality areas are rare and unpredictable in their occurrence, and random sampling would often lead to sampling of weedy sites with a limited suite of native plants. All cemeteries marked on 1:100 000 topographic maps within the region were visited, as well as others located through local information. These were sampled if they retained apparently little-disturbed native vegetation with relatively low weed abundance, but rejected if they were unfenced or clearly disturbed through cemetery operations or livestock grazing.

TSR samples were selected after reconnaissance surveys of a wide range of travelling stock reserves throughout the main study region, including the most promising areas based on floristic information from vegetation maps (Moore 1953a, Beadle 1948), unpublished surveys (A. Nowlandt, R. Rehwinkel pers. comm.) and local Rural Lands Protection Boards. We aimed for good coverage of the region and at least 8 TSR samples of grassy woodland per overstorey type (see below). Within these criteria, we sampled the highest quality sites, as judged by low weed abundance and high native cover and richness, that we could locate within the time available.

As described above, sampling was stratified on landuse (TSR/roadside, cemetery), and to ensure the range of overstorey species was represented (Bimble Box, Grey Box, White Box, Tablelands Yellow Box/Red Gum, Slopes Yellow Box/Red Gum). Owing to the paucity of high quality cemetery remnants, samples included sites with mixtures of these overstorey species, and resulted in a minimum of 7 cemetery and 8 TSR samples containing each overstorey species. The final sample included 33, 32, 31, 23 and 15 sites containing Yellow Box, Red Gum, White Box, Grey Box and Bimble Box respectively (including mixed sites), and 39 cemetery, 5 roadside and 38 TSR remnants. Several Fuzzy Box sites were also sampled, but these were not sufficient for describing understorey in these woodlands. It was not within the scope of this study to stratify on environmental variables such as lithology or soil type, but these variables were used in subsequent data analyses.

Sampling methodology

Small, well defined remnants such as most cemeteries and smaller TSRs were surveyed across their full extent, provided they were relatively uniform in soil type, topography and overstorey. Anomalous areas such as creek lines, swamps or graves were excluded. For larger, more continuous sites, particularly travelling stock routes and roadsides, relatively uniform sections were selected, with selections favouring areas of lowest exotic species abundance. Where possible we chose to sample larger areas rather than smaller quadrats because this was more effective for detecting native species that are often sparse in grazed sites, and because it provided a more complete record of discrete remnants, and thus was valuable for conservation planning and management purposes. This led to a high variation in plot sizes (0.04 to 56 ha, mostly 0.1 to 5 ha) that required consideration during data interpretation. However, correlations between plot size and relevant floristic data were generally very weak (see results).

Each survey area was visited once, in most cases during spring (1991–2001), and all species of higher plants observed within it were recorded. The survey area was traversed over its widest dimensions, until few new species were being added to the list. After traversing the survey area, a subjective abundance measure was allocated to each species, using the following scale: 1, rare; 2, uncommon; 3, occasional; 4, common; 5, very common (as per Prober & Thiele 1995). One of us (SMP) allocated abundance measures at all sites, to maximize consistency of scoring. Taxonomy follows Wheeler et al. (2002) for grasses, Bayer (2001) for *Xerochrysum*, and Harden (1990–3) for other species.

The following environmental attributes were recorded for each site: latitude, longitude, elevation, topographic class (an ordered sequence from hilly, undulating-hilly, undulating, gently undulating, to flat), landuse (TSR, roadside, cemetery), degree of tree clearing (wooded, thinned, almost fully cleared), lithology (according to 1:250 000 geological map sheets), and soil resource class (arable, suitable for grazing only, unsuitable for agriculture, according to the 1:1000 000 dyeline of Soil Resources Sheets 1 and 2, Soil Conservation Service of NSW). Rainfall in the study region generally declines, and temperature generally increases, with distance inland (Moore 1953a, AUSLIG 1990b, Austin et al. 2000), thus distance of the site from the coast was estimated from maps as a surrogate measure of these climatic influences. For interpreting analyses of understorey data, sites were classified into the following overstorey groups, based on the combinations that occurred in final set of samples: *Eucalyptus blakelyi/melliodora*, *Eucalyptus melliodora*, *Eucalyptus albens/blakelyi/melliodora*, *Eucalyptus albens*, *Eucalyptus albens/microcarpa*, *Eucalyptus microcarpa*, *Eucalyptus microcarpa/Eucalyptus populnea*, *Eucalyptus populnea*, *Eucalyptus conica*. While these groups are discrete classes, they formed an approximate east–west sequence that could be used for vector fitting (see below). Botanical region of occurrence (Southern Tablelands, Central Tablelands, South Western Slopes, Central Western Slopes, South Western Plains) was determined from Harden (1990–3).

Richness and relative abundance of various plant groups (natives, exotics, native shrubs, native annuals, native plant families) were calculated from the floristic data. Relative abundance was estimated by summing abundance scores for species within each group, and expressing this as a percentage of the sum of abundance scores for all species at a site. Relative rather than absolute sum of abundance scores was used to help correct for variation between samples in total cover and in sample area.

Data analysis

Classification of floristic data

Floristic data were subjected to the UPGMA cluster analysis procedure of PC-Ord (McCune & Mefford 1999), using the Bray-Curtis coefficient of dissimilarity. The Bray-Curtis similarity measure excludes shared species absences when calculating distances between pairs of plots. This renders the analysis less sensitive to species richness of sites, which may be affected by the variation in plot sizes in our dataset. Tree species were excluded from analyses because understorey patterns, including correlations with overstorey type, were the main interest of the study.

Ordination of floristic data

Ordination techniques were used to explore patterns in the full data set, and in two data sub-sets ('eastern' and 'western' Box woodland) determined from the full analysis.

For all data sets, quantitative floristic data (excluding tree species) were standardized to equal maxima and used to produce a distance matrix using the Bray-Curtis coefficient of dissimilarity (Faith et al. 1987). Non-metric multi-dimensional scaling (nMDS) analyses were performed on the distance matrices using the software package DECODA (Minchin 1989), and results were transferred to PC-ORD (McCune & Mefford 1999) for plotting and visual analysis. Preliminary analyses were performed in one to five dimensions using 10 random starts and global nMDS, and the 'minimum stress' solutions from each of these analyses were used as single starting configurations for hybrid nMDS in the respective dimensions. The two-dimensional hybrid nMDS solution was chosen for the analysis of the full data set, as recovery of ecological gradients was only minimally increased in higher dimensions. Three dimensions were necessary to best explain patterns in the two data subsets.

Correlations of environmental attributes with the distribution of sites on the final ordinations were examined by plotting each directly onto the ordination and, where appropriate, by calculating vectors of maximum correlation (R_{max}, see Prober & Austin 1991) using the vector-fitting procedure of DECODA. Monte-Carlo tests, using 1000 random permutations of the data, were used to estimate the significance of each vector correlation. Where appropriate, vectors were used to order sites and species into two way tables indicating species contributing to relevant trends.

Species diversity statistics

We generally avoided analysis of species diversity statistics in this study, because of the complicating influence of plot size. However, as correlations between plot size and floristic and environmental variables were generally very weak (see results), we present some comparisons of diversity of specific plant groups (plant families, annual natives and shrubs) with environmental variables.

Results

A total of 538 species from 82 plant families was recorded from the 82 survey sites, including 368 native and 170 exotic species. The most frequently recorded species included the natives *Elymus scaber, Austrostipa scabra, Lomandra filiformis* and *Bulbine bulbosa*, and the exotics *Hypochaeris radicata, Lolium* spp., *Bromus molliformis* and *Echium plantagineum*, which all occurred in over 60% of sites. Species with the highest mean abundance were the native grasses *Austrostipa scabra, Themeda australis* and *Poa sieberiana*, and the exotics *Lolium* spp. and *Hypochaeris radicata* (mean abundance 2 to 2.4). Native plant species richness ranged from 24 to 76 species per sample (mean 43). All sites contained exotic plants (range 5 to 53 species, mean 25), suggesting that no remnants of grassy Box woodland in the region have escaped the influences of European settlement.

Ordination of the full dataset indicated two major trends in the floristic data, the first relating to climatic gradients and lithological changes along the east-west gradient, and the second relating to landuse (Table 1). Analyses of data sub-sets were generally consistent with the full analysis, and thus are discussed in more detail only where exceptions or improved resolution were noted. Similarly, the UPGMA cluster analyses generally reflected the most prominent trends indicated by the ordination. Note also that, while exotic species showed significant trends on the ordination, similar ordination results were obtained when exotics were excluded from analyses.

Table 1. Correlation (R_{max}) of environmental and floristic variables with the ordination of the full dataset and the eastern and western data subsets. Significance of correlations are indicated by *(p<0.001), **(p<0.01), *(p<0.05).**

	R_{max}		
	All data	Eastern	Western
Variables	n=82	n=45	n=32
Environmental			
Distance inland	0.84***	0.81***	0.75***
Elevation	0.79***	0.77***	0.35
Topgraphic class	0.72***	0.26	–
Landuse	0.68***	0.89***	0.69***
Latitude	0.45***	0.58***	0.76***
Soil resource class	0.32*	0.29	0.19
Tree clearing	0.31*	0.35	0.24
Sample area	0.30*	0.46*	0.65*
Floristic			
Overstorey type	0.83***	0.69***	0.73***
Relative exotic species abundance	0.76***	0.87***	0.65**
Relative native shrub abundance	0.73***	0.75***	0.86***
Native shrub richness	0.66***	0.67***	0.84***
Relative native annual abundance	0.63***	0.71***	0.87***
Native annual richness	0.52***	0.69***	0.88***
Native grass richness	0.37**	0.4	0.69***
Total native richness	0.24	0.35	0.76***

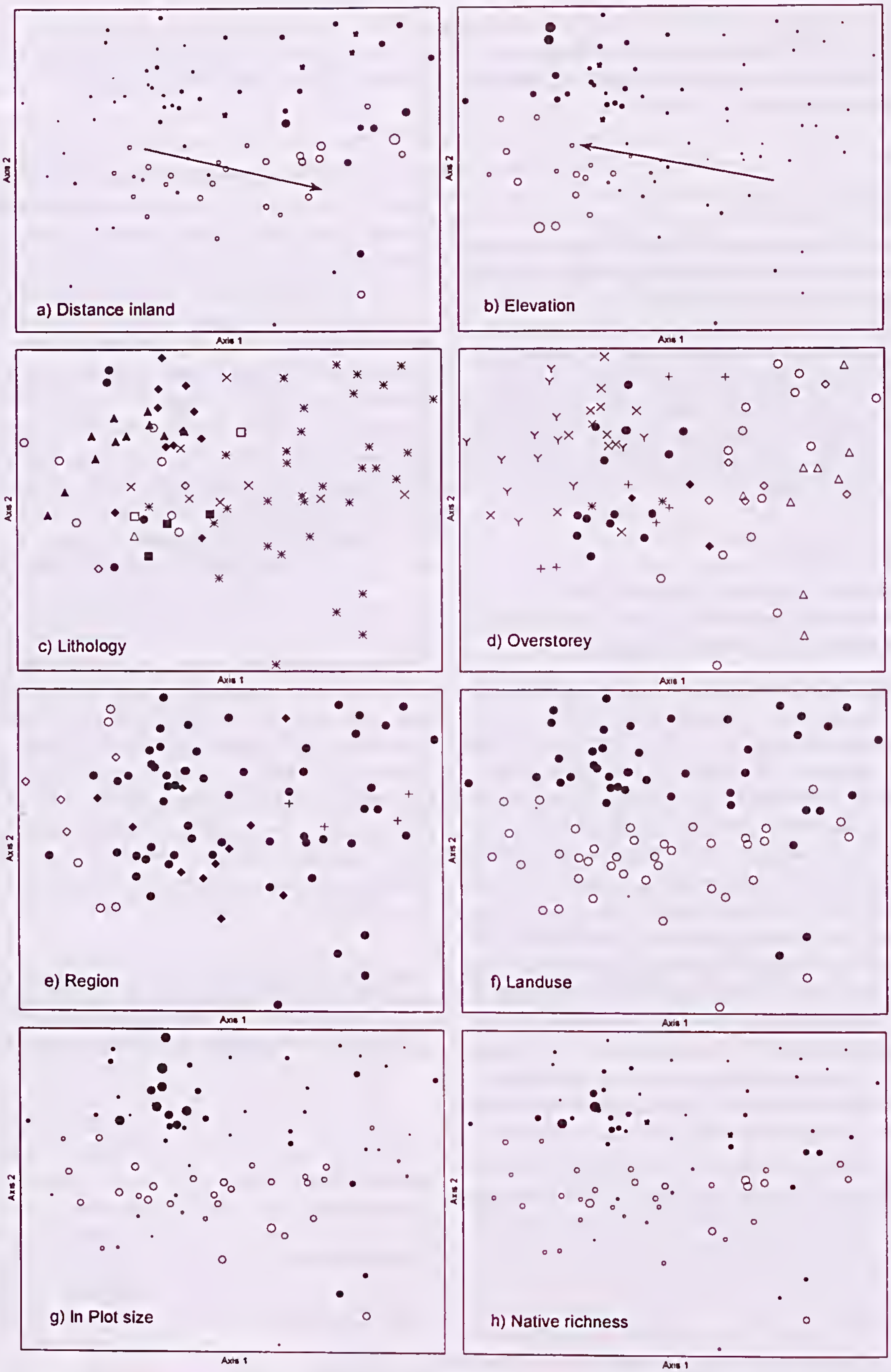

Fig. 2. MDS ordination of the full dataset showing trends in (a) distance inland (indicated by circle size) and landuse (● TSRs and roadsides,○ cemeteries), (b) elevation (indicated by circle size) and landuse, (c) lithology (igneous: ● alkaline volcanics (basalts), ▲ intermediate to acid volcanics (andesites), ■ intermediate to acid intrusives (porphyry),◆ acid plutonic (granites); sedimentaries: sandstones, siltstones, △ limestones; metamorphics: □ slates, schists, ◇ serpentinites; ✳ recent alluvials (or occasionally colluvial or eluvial); × mixed influences or uncertain), (d) overstorey eucalypts (see Fig. 1 for symbol key), (e) botanical region (◇ Southern Tablelands,○ Central Tablelands,◆ South Western Slopes, ● Central Western Slopes,+ South Western Plains), (f) landuse (● TSRs and roadsides,○ cemeteries), (g) plot size (ln, indicated by circle size) and landuse and (h) total native plant richness (indicated by circle size) and landuse. Vectors indicate direction and relative strength of trends in relation to the plotted axes.

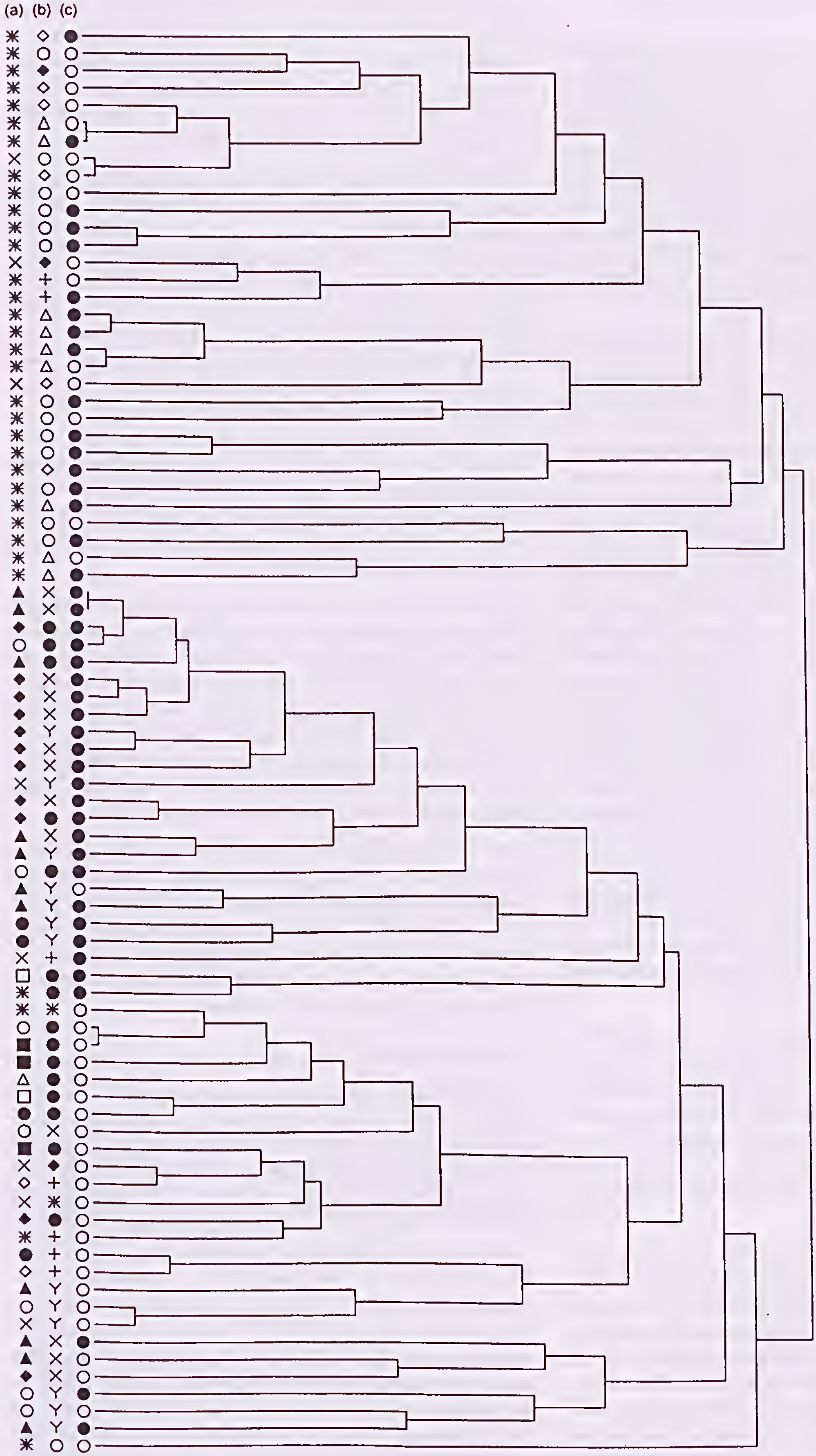

Fig. 3.
UPGMA cluster analyses showing (a) lithology, (b) overstorey type and (c) landuse. See Figures 1 and 2 for symbol keys.

Understorey trends related to climate and lithology

As could be expected, the strongest trend on the ordination of the full data set was a distinct change in understorey composition from the Tablelands in the east to the Plains in the west (Fig. 2a). Both climatic and lithological factors are likely to be important environmental determinants of the east-west trends. Increasing aridity is probably the most important of these, as reflected by the high correlation of distance inland with the ordination (Table 1, Fig. 2a). Elevation also declined significantly with distance inland, reflecting a grade from cooler conditions on the Tablelands to warmer conditions in the west (Fig. 2b).

The major influence of lithology was as a major disjunction between eastern and western sites (Fig. 2c). Eastern sites occurred on a range of lithologies, including alkaline and acid volcanics, granites, sediments, serpentinites and metamorphics, but there were no clear relationships between these and understorey composition. In the west, however, almost all sites had soils of Tertiary or Quaternary alluvial (or occasionally colluvial or eluvial) origin, largely corresponding with Red Brown Earths as described in Beadle (1948) and Moore (1953a) (rare in the east). As this lithological change from east to west closely parallels the climatic trends, it is difficult to separate the relative contributions of these two factors in influencing floristic patterns. However, a number of sources of evidence indicate that the change to alluvial soils significantly influenced understorey composition, over and above the climatic trends: 1) some relatively eastern sites had alluvial parent materials and these usually grouped with or were marginal to the more western sites on the ordination, 2) the change in understorey composition along the east-west gradient was most marked between the two main lithological classes (alluvial vs. non-alluvial), as indicated by the two major groups formed on the UPGMA cluster analysis of the floristic data (Fig. 3a & 3) the lithological change closely mapped a change in overstorey from White Box to Grey Box, as discussed below and as described by other authors (Moore 1953a).

Topographic class also changed along the east-west gradient, reflecting a grade from more hilly sites in the east to flatter sites in the west. The significant correlation of topographic class with the ordination of the full data set probably results from its correlation with the other major gradients.

Correlation of overstorey composition with understorey trends

The trend in understorey species composition across the east-west gradient generally paralleled changes in the overstorey (Fig. 2d). Yellow Box and Red Gum, sometimes with Apple Box (*Eucalyptus bridgesiana*), were generally the dominant eucalypts in sites falling to the far left of the ordination. Most of these sites were on the Central or Southern Tablelands, although some were in the far-eastern parts of the Central Western Slopes region (Fig. 2e). Adjacent to these on the ordination were sites on the Western Slopes dominated by White Box and/or Yellow Box, occasionally with Red Gum. Within the Slopes region there was little distinction in understorey between sites dominated by White or Yellow Box. The grade from Tablelands to Slopes woodlands was not clearly apparent on the cluster analysis (Fig. 3b), even when the eastern sites were analysed separately.

Samples of Grey and Bimble Box Woodland fell clearly to the right of other samples on the ordination (Fig. 2d). The distinction of these 'western' Box woodlands from the 'eastern' Box woodlands (dominated by White Box, Yellow Box or Red Gum) corresponds with the major division on the cluster analysis as described above, with one group containing almost all Grey Box (*Eucalyptus microcarpa*) and Bimble Box (*Eucalyptus populnea*) remnants, and the other containing all White Box (*Eucalyptus albens*) and Red Gum (*Eucalyptus blakelyi*) remnants, and all sites with Yellow Box (*Eucalyptus melliodora*) except for those occurring on the alluvial soils to the west (Fig. 3b). This change from eastern to western woodlands occurs within the Central and South Western Slopes regions (Fig. 2e), and is highly congruent with the change from non-alluvial parent materials to alluvial parent materials (Fig. 3a).

A grade between sites dominated by Grey Box and sites dominated by Bimble Box was apparent on the ordination (Fig. 2d), although these sites were interspersed on the cluster analyses (Fig. 3b), and sites containing both species occurred anywhere along the gradient (for both the full data set and the western data sub-set). This pattern was again related to distance inland, and became more pronounced when sites dominated by combinations of Grey and Bimble Box were ordinated separately (Fig. 4, see next section).

Five of the sites sampled contained Fuzzy Box, two as a dominant and three as a sub-dominant. These sites were scattered across the ordination amongst White and Grey Box sites, and formed no distinct understorey group of their own. However, sample sizes for Fuzzy Box are not considered sufficient to draw any reliable conclusions about the understorey of Fuzzy Box woodlands.

Understorey species contributing to the east-west grade

Floristic changes across the east-west gradient are shown in Table 2. Some species were ubiquitous across the whole sampling region, particularly the natives *Bulbine bulbosa, Dianella longifolia, Wahlenbergia luteola, Triptilodiscus pygmaeus, Oxalis perennans* and *Elymus scaber*, and the exotics *Hypochaeris radicata, H. glabra, Vulpia bromoides, Vulpia myuros, Trifolium glomeratum* and *Lolium* spp. However, most species (about 90% of those that were recorded with sufficient frequency) showed some relationship with the east-west gradient. These can be classified into three main groups: species distinguishing eastern from western woodlands; species contributing to the grade from the Yellow Box – Red Gum woodlands of the Tablelands to the White and Yellow Box woodlands of the slopes; and species contributing to the grade from Grey to Bimble Box

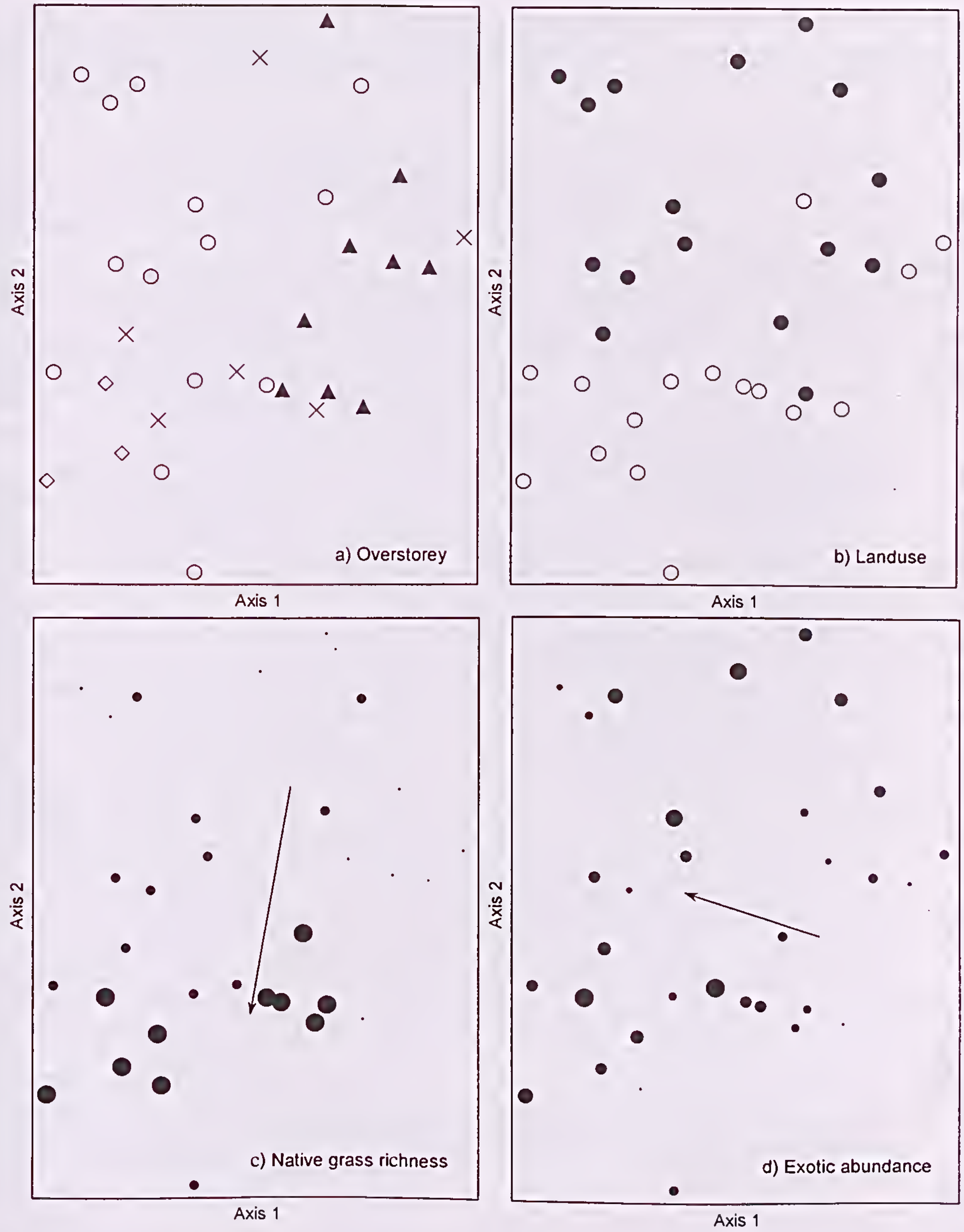

Fig. 4. MDS ordination of Grey and Poplar Box sites showing trends related to (a) overstorey type (◇ *Eucalyptus albens* & *Eucalyptus microcarpa*,○ *Eucalyptus microcarpa*,× *Eucalyptus microcarpa* & *Eucalyptus populnea*,▲ *Eucalyptus populnea*), (b) landuse (● TSRs and roadsides, ○ cemeteries), (c) native grass richness (indicated by circle size, range 5–16), (d) relative exotic abundance. Vectors indicate direction and relative strength of trends in relation to the plotted axes.

woodlands. As analysis of the latter data sub-set showed improved resolution of the Grey from Bimble Box woodlands (Fig. 4a), species contributing to that gradient are described using a two-way table resulting from analysis of the western data subset.

>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>Vector for increasing distance inland>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

Daviesia leptophylla	222-------------	-1--------------------------------	--------------------------------
Melichrus urceolatus	2--2-2----1-----	----------------------------------	--------------------------------
Centrolepis strigosa	-12--2----1-----	-1--------------------------------	--------------------------------
Ammobium craspedioides	-3--23--3-3-----	----------------------------------	--------------------------------
*Anthoxanthum odoratum**	---2--323--1----	----------------------------------	--------------------------------
Thysanotus patersonii	-11---------11--	-1--------------------------------	--------------------------------
Burchardia umbellata	23-333--323--1-2	31---1----------------------------	--------------------------------
*Holcus lanatus**	---322-23222---1	----------------------------------	--------------------------------
Gonocarpus tetragynus	222212--123-2--2	23--2-----------------------------	--------------------------------
*Myosotis discolor**	1----222222-----	-1--2-----------------------------	--------------------------------
Daviesia genistifolia	--2-2-----1---3-	--------1-------------------------	--------------------------------
Ranunculus lappaceus	2--3232-2--2--22	---3--1-3-------------1-----------	--------------------------------
Hardenbergia violacea	1----1----1-----	-1----11--------------------------	--------------------------------
Microlaena stipoides	3-2-----2-------	-23-----2-----3-------------------	--------------------------------
Austrodanthonia pilosa	----1-2-2--1---3	---2------------------------------	--------------------------------
Eucalyptus macrorhyncha	**1----3-1-13-----**	**2---2----------3------------------**	**--------------------------------**
Thysanotus tuberosus	22--1---1-1--2--	----------1-------2-------------2-	--------------------------------
Eucalyptus bridgesiana	**-31--233--2-1123**	**-3123-------3----2----------------**	**--------------------------------**
Schoenus apogon	1-2222--1-2-1--1	331-11-112--2----2----------------	--------------------------------
*Acetosella vulgaris**	-----2222-21--2-	-2--21-2----1-1-------------------	--------------------------------
Hypericum gramineum	-22222--11312---	-2-221-1222-1----2-------1--------	--------------------------------
Cryptandra amara	-2-23------3--32	------1------2-------1-2----------	--------------------------------
*Phalaris aquatica**	---22----1-2--13	---1----1-1--1-------1------------	--------------------------------
Ranunculus pachycarpus	-2---2----2-13--	-2--------------------------------	2-------------------------------
*Linaria pelisseriana**	1----2----1--1--	11-2----------3------------------	--------------------------------
Eryngium rostratum	---1-----122-11-	-1---1-----------------------1----	--------------------------------
Drosera peltata	223313-1323--2--	331-22-2-222---2--------1---------	32------------------------------
*Dactylis glomerata**	--122--21-1---22	-1---1-2----2-3--2----------------	--------------------------------
Craspedia variabilis	-2-33---------23	21--------------------1-----------	-------2------------------------
Luzula meridionalis	32232212223-22-3	33-2231222212-2222---22-22--------	--------------------------------
Eucalyptus blakelyi	**32332333344-12-3**	**433-5232--334-23-3---3-133-----1--**	**--------------------------------**
*Vicia sativa**	----21-22223--3-	--13---132-2331-----21------------	--------------------------------
*Moenchia erecta**	11--------2-1--1	233-21-2--2---12-1-1--------------	--------------------------------
*Medicago lupulina**	------23-32-3---	332-2--3--3----2--1--2----2-------	--------------------------------
Ajuga australis	-----2---------2	-1-1------1--------------------1--	--------------------------------
Acacia dealbata	---3-----122----	-1-21-----------------------------	------------2-------------------
Leptorhynchos squamatus	-22342212-322333	22-2-2--2-1-1----12---3--2-233--2-	2-------------------------------
Geranium solanderi	---2--22--22-12-	2--321224-22222-3-----2-----2-----	--------------------------------
Diuris punctata	-2-----------1--	---------1--------1------------2--	--------------------------------
Aphanes australiana	-----11---------	-21-2-------1--21--1--------------	--------------------------------
*Briza minor**	2323231233322212	3332232312433-233-12132-33----2212	21--1---------------------------
*Plantago lanceolata**	--143-222212--13	1242-4-41-2-4-3-34-2-3-1-42-------	--1-----1-----------------------
*Cerastium glomeratum**	2----211--2-11--	-33-23-2--3-21223--2--1---2-1--1--	--------------------------------
Acaena agnipila	12-22212--2-1223	222222232212223223-22321-22---2---	--------------------------------
*Cynosurus echinatus**	-1-------12-1---	321-22-2--2---2-22-------2--------	--------------------------------
*Parentucellia latifolia**	--2--213--1-1--1	233-22-3-12-2--23--2-2-----------1	1-------1-----------------------
Microtis unifolia	-11--2-2--1-12--	-2-1--2-11--21------1---2--2-111--	--------------------------------
*Hypericum perforatum**	1--22--21-2-1---	222-12-3---13-2-2312-2-1-2------1-	------1-------------------------
*Geranium molle**	------------2---	152-3--3----1--43--3--------------	--------------------------------
*Sherardia arvensis**	---1-222-22-3---	332-33-3--3-3-2343-2-2---22-------	------------------2-------------
*Rosa rubiginosa**	------11--1---2-	1111-1-22-1---2111-2-2---1----1---	--------------------------------
*Trifolium subterraneum**	-1-1--22323----3	233-3313--332-213--3132--32-------	-----2-----------------------1--
*Poa bulbosa**	--1---1---3----2	-23-22-2---2--122--1-2----2-------	------------------1-------------
*Briza maxima**	532224--454----2	2---22231--42-4--4-1-2-13--52--3--	---35---------------3-----------
Plantago gaudichaudii	--------11-1--3-	----------------------------------	----2---------------------------
*Centaurium erythraea**	---12-1----2--2-	---2-----2-------1----------1-22-2	--------------------------------
Themeda australis	3555523452454555	43-5134-3522243--1535-555--534-55-	33--2------23-2------------3----
*Trifolium striatum**	---21-13---1---2	-----1--------2----2------------23	--2-----------------------------
*Anagallis arvensis**	2-2--2---22-12--	222222-2-233223-22122--2-122--23-2	--------11----------------------
*Silene gallica**	---------1---1--	2----1-2---1---311-1------1----1--	--------------------------------
*Paspalum dilatatum**	---1----1------1	2-11-222--1-1--------1----------1-	-21-----------------------------
Eucalyptus melliodora	**2-2123--1242-222**	**--215--2-25-3----3---33-233--3-33-**	**313-2-1-------------------------**
Indigofera adesmiifolia	----------------	-1------2--1-------1---1----------	--------------------------------
Pimelea curviflora	122-2-----11-222	------2-3---11----3-1--11---33----	1--2----------2-----------------
Solenogyne dominii	--2-21-1----2--2	32-3--1--2-1--------1---2------1-	2----122------------------------
Geranium retrorsum	12--222222--33-2	23-2-232223-132-3-323-3321-333-22-	22-21----2----------------------
Microseris lanceolata	22-2-2----2124-3	12-21-2-3412-2-1--4-3-322---43-33-	3--1-------3--------------------
Austrodanthonia racemosa	--------------2-	--------2----------1--2-------1---	--------------------------------
Eucalyptus albens	**-2----------31--**	**354335145-2543545-1413-32--35-52-4**	**-1--1---------------------------**
Asperula conferta	1--22-332322-122	2222-332223-223-3-323222222-2--3--	2-----2-----1----2---2------2---
Dichelachne micrantha	--2-3-------1-22	-2---12-323-------3-2---2---3--3-1	----21----1---------------------
Templetonia stenophylla	-------------1--	---2--1-1---1----1-1-------------	2-------------------------------
Cynoglossum suaveolens	-----2111--111-2	121111-2222-1-122221112121111-1--1	-----------1---------1------1---
Acacia implexa	----------------	-------1-1--111----2----------1---	--------------------------------
Wahlenbergia stricta	---2------1223-2	---22---23------31------2--2---3--	----2--1---2--------------------
Desmodium varians	------1---1----2	22--21-12-21---1112-----2--2------	----------21--------------------
*Aira elegantissima**	33343423333-2533	3331422313333-254-22233342-31-223-	-323312---222-212--3--2---------
*Trifolium campestre**	-233242-33321222	3322232332333233223333323443333333	-4-321--2-2---1--------2--------
*Cirsium vulgare**	----2---1122--21	2-1222121-2-2-2--1-1-11--1------12	-1--2-1--1----------2-----------
Juncus subg. genuini	3-11-2--2-2-----	222-1422--231-1-2--2-1--22--------	-1--2-2-2----21-----1-----1-----
Senecio quadridentatus	---21-----22----	----1--122-1-12---21---2-----1----	---1-----1-----------1----1-----
Goodenia hederacea	222-------------	-1--------2-------------11--------	----3---21--1-------------------
Plantago varia	2--2-232--3-13-2	-21323123-332-32433322222-1-33--12	32---12--2----1--2---2----------
*Orobanche minor**	------------1--1	-2-1-1-1222-2-1-1121---1-1-31-1-11	-1------------------------------
Hydrocotyle laxiflora	222--211212-32-3	2323122132333232232-112-22-3223322	3----12-2131---11----1--1-------
Wurmbea dioica	2--1-3----2-2-11	121----2-2-31--1-----1----2-------	------22----------------11----2-
Rumex brownii	----2-122222-122	232-2222212211231121-22-122---12-1	-11-2-2---1--2-11----1--------1-
Caesia calliantha	---2------------	-----1----------------3----1-2--2-	--------------------------------
Poa sieberiana	2434322323352354	-2-4-2435323254-32535-554-24455433	22-23-1--4333-4-1---2---------1-
Tricoryne elatior	222322--1232-222	32-1213212221-12-3----3233---2----	-2-2222-1122---22--2------1-1---
Cymbonotus lawsonianus	----11--1-2-2--1	22-12-222222---11-21212------2-2--	-----1----1-----1----22---------
Bothriochloa macra	-------2-------2	321-21-3--233-43-2-1-----3------22	--2---------2-------------2-----
Stackhousia monogyna	-2--22--2-22-422	21-1122-22---1--2-312-2-3111-2-2--	32-22----222--21----------------
*Petrorhagia nanteuilii**	-----22--23-1111	22-12--21222222221313-2321222-33-3	---112----2----1----2-----------
*Trifolium angustifolium**	-1--2232-3--1-22	22-1-212--132-2--2122312223-1-2-23	--32---2------------2----------3
*Romulea rosea**	----2--2-----2-2	-34-25-3--2-1-3-23-3-4---32-----3-	3342------2-----11--------------
*Trifolium scabrum**	--1--2----------	-----------3----3-1-2-3---4-1-12-2	------------------1-------------
*Bromus molliformis**	11-2-21323332-23	344234252232334243122442-52-312232	-222--12--11---12---3222-----22-
*Trifolium arvense**	-122-33-21223422	2221232-222322-33-323232214423-421	-2222223--21-2122--2--------1---
Lomandra multiflora	11-122----121322	12-1-21-12221-1-1122---22--212-2--	22-12-----112-2-2--12-----------
Lomandra filiformis	323-231-223-232-	222223-22133212222231322322-2231-2	-1-22311222221-12-22--2---1-----
Chrysocephalum apiculatum	-32122112-332243	-2----213221323-3-3-2-233-2343-32-	22-23-1--2232------1-------22-1-
*Chondrilla juncea**	-------1--1----1	22-12-32123-11131-21221-22--11-2-1	-1---11--1--1--21------------1--
Aristida ramosa	1-2-------2-----	3----2----241-222--3-1--3332------	3----3---2-2----1-----------1---
*Bromus diandrus**	2---22--33321---	15522344215322324414133235-3133-32	23323-22231---2231----22--------
Bulbine bulbosa	-3-31-313432152-	2212233132242222413-212-31-23-12-2	32-1-2244222--222--2-11-2-11----
Glycine tabacina	----2-----1--2-2	----2-1-22--2-1--22-2112211-2-12--	------221------------1-----11---
Dianella revoluta	233232----23--32	-1-3-13-4--3-32--24-2--34--232--3-	33--32--12-24---1---3-----24----
Linum marginale	-----------1-212	---2-1--3---2----1112--2--2223----	-----------1------2-----------2-
Glycine clandestina	-2--------11--1-	-2----1-322121--13-1--2-21-22-22-1	1---1------1---11--1-1-----11---
Dichopogon fimbriatus	-------2--22-113	322--42-42311-224331232221-33223--	32-3222-3-23--2-2--2------------
*Hypochaeris radicata**	2-33332323222223	2323332322334223343222323312-2-222	222322222133-212--23-22222-222--

Table 2. (Begins on previous page) Two-way table indicating changes in floristic composition across the east-west gradient. Sites are arranged according to the distance inland vector, and species according to their weighted average location along this vector (based on abundance data). All species occurring in more than 12 sites are included, as well as selected others. *denotes introduced species.

*Hypochaeris glabra**	-12-221--22-31-2	331--2---1322-232-22222-22-1-32-33	2223-2-22-32--12---3-2--1-------
Diuris dendrobioides	----------------	--------------------2---2--2-2----	--------------------------------
Carex inversa	-----21-2-2-1---	331113232-322-2111-2----------1---	----2-2------2----1-22---3---12-
Austrodanthonia eriantha	--2----2-22-----	---------1----2--------3----------	-33--2--3--------------2--------
Arthropodium minus	-11--2----2-31--	13-2--12-222--33--2-1---2-----22-2	----23-321---1---21------1----2-
Convolvulus erubescens	------2-1-212112	221222-2332-22312323323222-2232223	-113-1-11--2--1112----11-11-2--2
*Salvia verbenacea**	---------------2	-23112-3-12-34314122222-23222-122-	1331--221-----111-1-----1---2---
Austrodanthonia carphoides	----------------	1------1---------------2-1-2----2-	--2-----------------------------
*Carthamus lanatus**	----------------	-22----2--3----12-1-2----1---31--2	------1---11----1----2----------
Dianella longifolia	-21222--21221312	-2-2-22-32-2122-1-2-2-3222-323122-	---2222--222--3-1---11--22232-1-
Eucalyptus conica	----------------	---------2--------1------------3--	-------------2--1---------------
*Vulpia bromoides**	-2-521-333-322-3	332-22-21-334-234412-423544-31---2	-3-3-4-2324-22444314-2--2----222
Wahlenbergia luteola	----2--2--221322	23-2-2433--2223-22424322223243232-	222-22-222222-2211-2-1--2-2-2-3-
*Vulpia myuros**	--2-2223-2----3-	-------2-2--1--22-1-23----232322-3	--4--232--24---2--1---3--2---1--
*Avena fatua/barbata**	-------23-3--112	2352-343123-22424313-54342-42332-2	23332232-333-133322---3-222----3
Austrodanthonia setacea/spp.	2-3--23322--3---	33---2--2-424--232--232---2-4-----	444-2325232-35----323-42---3-242
*Trifolium glomeratum**	--22-2-3--1--2--	----2--21------1--2-22--22---2-1-2	-21---232-2--2-2-2-2---22---2---
*Arctotheca calendula**	--2--1---12--1--	323-32-2--2---223--3-2-1--1--2----	2----1-33--2-2----2----322-1-13-
Triptilodiscus pygmaeus	212122-11-3-11-1	321-31----2----32--------122-2-32-	----1-132-43--122213-22-2---212-
Oxalis perennans	2-22-21-122-2--2	23--22-111222-2232-3-12-22--2222-1	12-222222123-2-1222--2212-2122-3
Acacia decora	-------------1--	-------1-----1-1---2-------23--1--	---3-1---------21---------------
Brachychiton populneus	---------------2	---11-212--22--11-----122--11-12--	1-1-------111---1-------1-121-1-
Elymus scaber	--2-221122221122	2212--22322-3221233222222313333-13	2-2222322222-332331212-222-2-323
Lolium spp. *	--22-232232-2-2-	242222-322433143331325223242324225	-33144533244-32332224324253--243
Chrysoceph. semipapposum	--------------2-	--------1----3------4--4---1------	----2-----1---122--2----1-------
Vittadinia muelleri	----------------	--------------2----------1----1-1-	-----------1-2------------------
*Echium plantagineum**	------211111----	335223-3--2--1234112-311123--3-222	221211133-23-1-22121222222311221
*Marrubium vulgare**	----------------	-2--------1--1----11------1-1-1---	---------------11---------21----
*Sonchus oleraceus**	--11------11----	1--1-1-11--1--21-1--111-----11-213	21--112--232-1--1-11----1222----
Vittadinia gracilis	----------------	-----1---1----2-1-----2-21--2---21	-221--2-1------22---2-1---------
*Medicago minima**	----------1---2-	---3-1---2-222-12-112-----2-2-21-3	---2-232---1-22421---3------123-
Goodenia pinnatifida	---2----1----1-2	21-----21-3-1-3-32212322-232212321	221223122212132--32--22322--2222
Cassinia arcuata	------------1---	-1------1-----1--1----------------	3-----------4-------3-----------
Dichondra repens	------1---------	-----2----2-----1--2-----2----22-2	-----12--2-2---21---------12--1-
*Hordeum leporinum**	-------1--2-----	132-2--2------2-2----31---3--1-12-	22--------12-2-2111--2-3-2---222
Cheilanthes sieberi	-11---------21--	12-1--1-121211-42-212-2231-31113--	22-22-1211222-222-22222-2-22223-
Daucus glochidiatus	-----31---3-2---	-2-2---2---2-22--21-------2-222---	1--1-2-22-33--2-21-3-2223-1222--
Austrostipa bigeniculata	----------------	-12--3--------4-33-3--3-1--312--2-	--532---2245--323143-----------2
Acacia deanei	3-2-1----------3	-----------------1---------2------	3---3---2-22--2-3-22--2-2-12----
Austrodanthonia auriculata	---------1------	3-1-3--2----2--3-----22212----1123	-3-43-412232--354-23--2-2-----2-
A. bipartita/fulva	---2------------	--------------2--2----------------	22--2----2--2-2-----2-----21----
Austrostipa scabra	2-2------22---1-	23-221-212322-2222-1-2223323343333	3434442434343243433444445-344423
Vittadinia cuneata	----------1--2--	-------11-11-----2--31--2-1-32122-	--313-322----223-3---1-121--2-21
*Lepidium africanum**	----------------	-----1--21---1-------------1------	-11-1-11-2---1-11-1-----1-2-----
Aristida behriana	----------------	1-2--------------1---121-2-22--222	-2232-222-21--222--3----2-2---1-
Xerochrysum viscosum	----------------	-1-------2-2----2-------1-----2--1	-----2------3-3-----2-----22----
Austrostipa nodosa	----------------	--------2-----2----1----1-2-1---11	--2------13-2-1-2---1----2----2-
Wahlenbergia gracilenta	----------------	----------------1--2---1-------1--	----------2---1--------------2-1-
Brachycome heterodonta	----------------	---------1---------1--------3-----	-----------------3-------------2
Crassula sieberiana	------1-----1---	-2--2------11--21---------1----3--	-----2122-22-1-1--13-33231--22--
Austrodanthonia caespitosa	---2-----------2	----3------------2-2----232--31334	-2243-4-4232-23345-3-3-333--2325
Chloris truncata	-------------1-1	1-----------------1------------11-	--1------------21---------22---2
Einadia nutans	--2-------------	-1-----1----1--11-11---21-112--3-1	-122212-233--12232-232223223122-
Callitris glaucophylla	----------------	----------------1-----3-2--23225--	31-5523-22553-42211533--2--4313-
Sida corrugata	----------------	----------------------2--21-2--22-	-22211222132-21222-111222---22-1
Calotis lappulacea	----------------	-------1----21-1------2--222-3----	-21--1-23---32---22-232-2-32233-
Eremophila debilis	----------------	----------------------------3-22--	-1-12111--22111-2--2312-1-21----
Dodonaea viscosa	----------------	--------------------2----------2--	3---32---3224-41-11-3-----23---2
Eucalyptus microcarpa	----------------	------------------------2---------	33-3341435-23331332-5-33------33
Maireana microphylla	----------------	--1--1----------1---------2-------	------112-1--21-13-13-41-2-----1
*Medicago truncatula**	----------------	---------------1------------------	-------12----2---2-1---2-------3
Wahlenbergia communis	--------2-------	----------1--------------2--------	---1--2----2-----22--21222--12-2
*Hedypnois rhagadioloides**	----------------	------1-------------1------------2	------133--2---21-------3---223-
Calotis cuneifolia	----------------	----------------------2---2------2	3---322-3-33314-22-2232-2--32332
Sida cunninghamii	----------------	------------------------------1---	-----1----11----2-21-1---1--1---
Erodium crinitum	----------------	----------------2--------------1--	---1-1----12---1--2--22-12--31--
Enteropogon ramosus/acic.	----------------	------------1---------------------	35-542432334-244322333235432234
Maireana enchylaenoides	----------------	----------------------------------	--1-1----32---212-2------------2
Xerochrysum bracteatum	----------------	-------------------------------2--	2---2-1---33---22--2-3--3---231-
Austrostipa verticillata	----------------	-------------------------------2--	1-------------------1-----32----
Vittadinia cervicularis	----------------	------------------------2---------	----1----2-----112----1--112---2
Asperula cunninghamii	----------------	----------------------------------	-----2----3-2-----21----1------2
Senna artemisioides	----------------	----------------------------------	---2-2---233-223----2-----23-13-
Stuartina muelleri	----------------	----------------1-----------------	-----1-12-1-------12----1---212-
Austrostipa elegantissima	----------------	----------------------------------	-----3----1----1--------------12
Ptilotus spathulatus	----------------	----------------------------------	-------1--1----111-2-----------1
Chenopodium desertorum	----------------	-----------------------------1--21	-211-----2221-2222-221212-242222
Thyridolepis mitchelliana	----------------	----------------------------------	---2------12---1--3-------211---
Minuria leptophylla	----------------	----------------------------------	-----2----22--212--2-1--4-----2-
Sclerolaena muricata	----------------	----------------------------------	-------1-----2---2-----1-------1
Aristida benthamii	----------------	----------------------------------	-1------3---------3--2-2----2-1-
Atriplex semibaccata	----------------	----------------------------------	--1---------1211222-2--2121--1--
Panicum subxerophilum	----------------	----------------------------------	---11-1---11---------2--1------3
Hyalosperma semisterile	----------------	----------------------------------	---1--1---22----2--3-2--3---31--
Geijera parviflora	----------------	-------------------------------1--	---1--1--------1--------2-12-2--
Goodenia cycloptera	----------------	----------------------------------	----------22---12--2-22-2---21--
Maireana humillima	----------------	----------------------------------	-------3--2--------1-1222---21--
Bulbine semibarbata	----------------	----------------------------------	-----3-12------------22--2---23-
Myoporum montanum	----------------	----------------------------------	------1---2-2-4-2--32-----23---3
Pittosporum phillyreoides	----------------	----------------------------------	-----1-----1----1----------1--2-
Brachycome ciliaris	----------------	----------------------------------	-----2-------2---------3-------3
Eucalyptus populnea	----------------	----------------------------------	---1--4---32---2---3-3-33342143-
*Sisymbrium orientale**	----------------	----------------------------------	----------21---11--2-1------222-
Calandrinia eremaea	----------------	----------------------------------	----1-----2--------2-1122---221-
Actinobole uliginosum	----------------	----------------------------------	----------1-----1--2-1--2---22--
Sclerolaena bicornis	----------------	----------------------------------	--------------222-2--32--1--2332
Plantago turrifera	----------------	----------------------------------	--------2--1--------12-121--2212
Rhodanthe corymbiflora	----------------	----------------------------------	-------1-----1---321---43---4213
Isoetopsis graminifolia	----------------	----------------------------------	------------------1--2-11---2-1-
Calotis hispidula	----------------	----------------------------------	---------------1--21--122---223-
*Medicago laciniata**	----------------	----------------------------------	--------------1----2--3132442331-
Stackhousia viminea	----------------	----------------------------------	---------------------2--1---2-1-
Paspalidium constrictum	----------------	----------------------------------	---------------------1-2----3-2-
Brachycome lineariloba	----------------	----------------------------------	------------------------122---2-
Menkea australis	----------------	----------------------------------	-----------------------122--22--

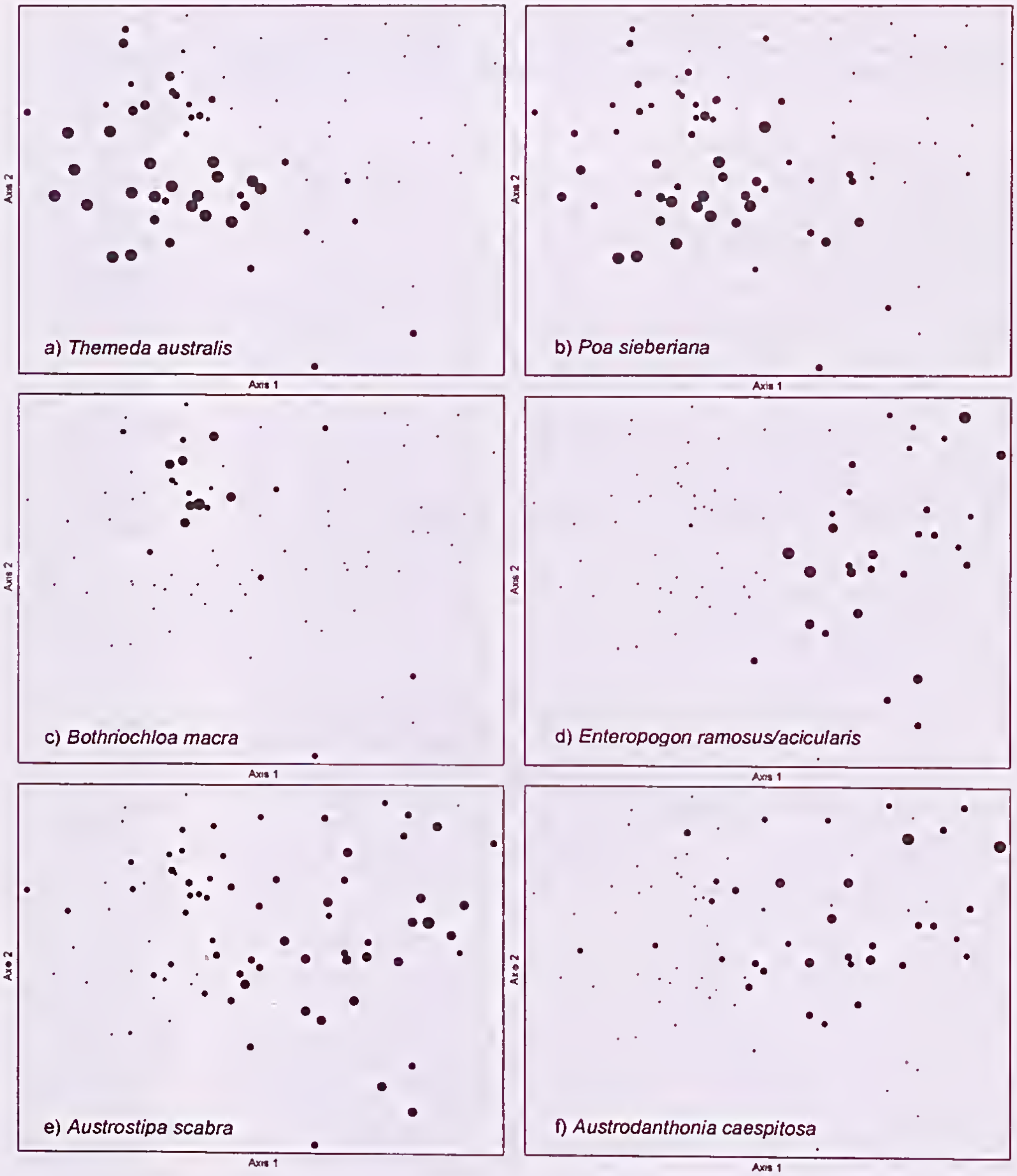

Fig. 5. Trends in dominant grasses. Circle size indicates abundance of:
(a) *Themeda australis*,
(b) *Poa sieberiana*,
(c) *Bothriochloa macra*,
(d) *Enteropogon ramosus/acicularis*,
(e) *Austrostipa scabra*,
(f) *Austrodanthonia caespitosa*

Species distinguishing eastern and western box woodlands

Differences in species composition between eastern and western woodlands involved changes in both the dominant grasses and subsidiary species (Table 2). In little disturbed remnants, *Themeda australis* and/or *Poa sieberiana* were the usual dominants in eastern woodlands, whereas in the west, these species were subsidiary or absent. The dominant native grasses in western woodlands were more varied, but generally included *Enteropogon ramosus/acicularis*[1], *Austrostipa scabra* and/or *Austrodanthonia* species (Fig. 5, Table 2). The only notable intergrades between these two groups concerned sites with a mix of White and Grey Box, and two remnants on alluvial soils the Junee–Coolamon region, where Yellow Box is often the sole dominant. These sites were generally intermediate on the ordination, and one of the latter sites grouped (along with a nearby TSR) with western woodlands on the cluster analysis, despite an understorey dominated by *Themeda australis*.

Total native species richness was similar for eastern and western woodlands, but changes in subsidiary species composition were substantial. A number of these trends in native species were consistent at the family level, with families such as Dilleniaceae (*Hibbertia* spp.), Haloragaceae, Epacridaceae, Ranunculaceae, Rosaceae (particularly *Acaena agnipila*), Orchidaceae (particularly *Microtis unifolia*), Juncaceae and Myrtaceae (mostly *Eucalyptus*) notably more frequent or diverse in eastern woodlands (Table 3).

Western woodlands were characterized by a notable increase in the diversity and abundance of species of the families Goodeniaceae, Crassulaceae, Malvaceae (particularly the forbs *Sida corrugata* and *Sida cunninghamii*), Chenopodiaceae (particularly *Maireana microphylla*, *Maireana enchylaenoides*, *Chenopodium desertorum* and

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[1] *Enteropogon ramosus* was the most common, but as they were not regularly distinguishable (especially on grazed sites) they were grouped together for this analysis.

Atriplex semibaccata) and Myoporaceae. Native species of the families Amaranthaceae (particularly *Ptilotus spathulatus*) and Brassicaceae (e.g. *Menkea australis*) occurred exclusively in western woodlands (Tables 2 & 3).

Other families showed a more even distribution across the east-west gradient (Table 3), but some species within these families were still important for distinguishing eastern from western woodlands (Table 2). In particular, species of the family Asteraceae (daisies) were common across the gradient, but some species (e.g. *Leptorhynchos squamatus, Microseris lanceolata, Cymbonotus lawsonianus*) were typical of eastern woodlands and others (e.g. *Calotis cuneifolia, Vittadinia cervicularis, Stuartina muelleri, Minuria leptophylla, Rhodanthe corymbiflora*) were frequent only in western woodlands.

Bimble and Grey Box woodlands had a generally higher diversity and abundance of native annuals than eastern woodlands. These included the daisies *Rhodanthe corymbiflora* and *Stuartina muelleri* and the lily *Bulbine semibarbata*, as well as a number of species more typical of the Bimble Box Woodlands (see below). Other natives more common in western woodlands included the forb *Wahlenbergia communis*, and the grasses *Aristida benthamii, Panicum subxerophilum* and *Paspalidium constrictum*. Other natives showing notable preferences for eastern woodlands included the forbs *Luzula meridionalis, Geranium solanderi, Asperula conferta, Cynoglossum suaveolens*, and *Wahlenbergia stricta*.

Owing to the lack of undisturbed remnants, trends in native shrub abundance across the east–west gradient were difficult to assess (cemetery remnants were often cleared of their mid- and over-storey species at least early in their history, and grazing and thinning in TSRs also affect the shrub layer). From the available data, it appears that shrub diversity and abundance was often higher in western woodlands (particularly evident in cemeteries) than in White Box Woodlands, and perhaps also increased again in the Yellow Box – Red Gum woodlands of the far east (Fig. 6a). Shrub species changed markedly across the gradient, with leguminous shrubs, epacrids and *Cryptandra amara* more common in the east, and shrubs of the family Myoporaceae (especially *Myoporum montanum*), *Senna artemisioides, Maireana microphylla* and *Pittosporum phillyreioides* more typical in the west. *Acacia* and *Cassinia* species occurred across the gradient (Table 2).

Exotic species were notably more abundant in the eastern than the western woodlands sampled, both in cemeteries and TSRs (Fig. 6b). A wide variety of exotic species common to eastern woodlands were absent or infrequent in western woodlands (e.g. *Briza minor, Plantago lanceolata, Cerastium glomeratum, Hypericum perforatum, Sherardia arvensis, Rosa rubiginosa, Trifolium subterraneum* and *Anagallis arvensis*). By contrast, few exotic species were characteristic of western woodlands only.

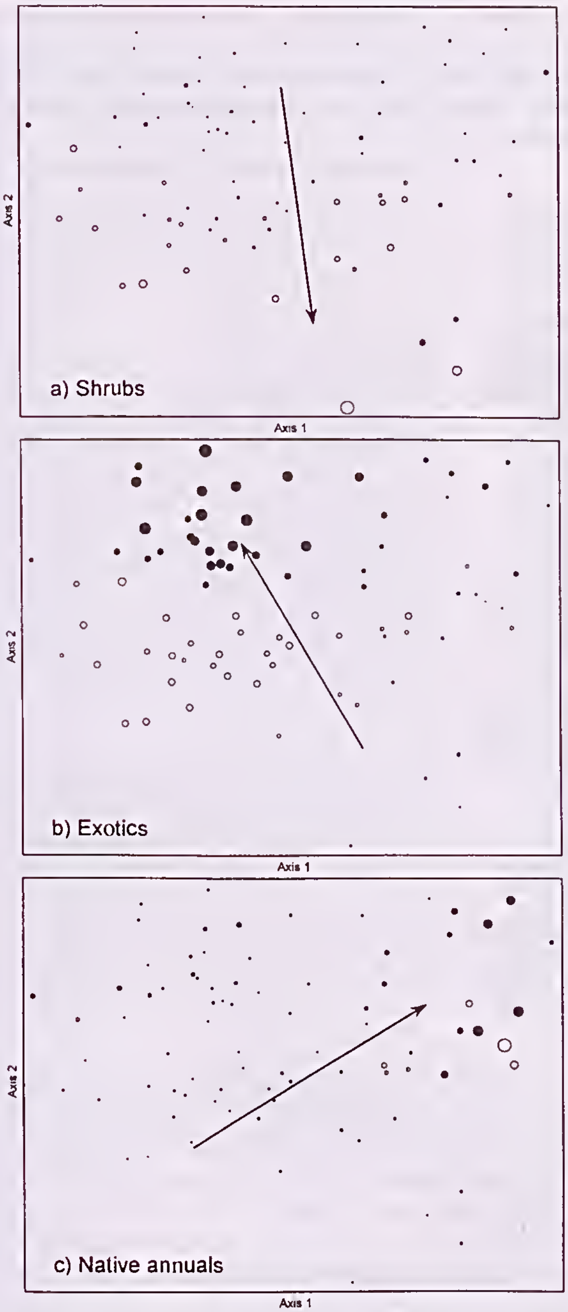

Fig. 6. Trends in plant groups. Circle size indicates: (a) Relative native shrub abundance (b) Relative exotic abundance (c) Relative native annual abundance. Closed circles indicate TSRs and roadsides, open circles indicate cemeteries. Vectors indicate direction and relative strength of trends in relation to plotted axes.

Species contributing to the grade from Yellow Box – Red Gum Woodlands of the Tablelands to White Box, Yellow Box, Red Gum Woodlands of the Slopes

Themeda australis and *Poa sieberiana* were the dominant native grasses in little-disturbed representatives of all eastern woodlands, thus the grade in species composition from the tablelands to the slopes was largely due to subsidiary species (Table 2). Only a small number of species (e.g. the native shrubs *Melichrus urceolatus* and *Daviesia* spp., the native forbs *Ammobium craspedioides* and *Plantago*

Table 3. Two-way table indicating diversity of native species (1–6 = 1–6 species respectively, 7 = 7–9 species, 8 = 10–12 species, 9 = 13–15 species) recorded for each family at each site. Sites are arranged according to the distance inland vector, and families according to their weighted average location along this vector (based on species richness data). All families with 3 or more native species recorded in the full data set are included. Selected data for eucalypt abundance are included to assist interpretation of gradient.

	>>>>>>>>>>>>>>>>>>>> Vector for increasing distance inland >>>>>>>>>>>>>>>>>>>>>>		
E. melliodora	2-2123--1242-222	--215--2-25-3----3---33-233--3-33-	313-2-1-------------------------
E. albens	-2----------31--	354335145-2543545-1413-32--35-52-4	-1--1---------------------------
E. microcarpa	----------------	------------------------2---------	33-3341435-23331332-5-33------33
E. populnea	----------------	----------------------------------	---1--4---32---2---3-3-33342143-
Dilleniaceae	1-1-1---1-----1-	------1-1-------------------------	--------------------------------
Haloragaceae	111121--211-1--1	211-1----1---------------1----1---	--------------------------------
Epacridaceae	1-11-2----2-----	1--------2-----1-------1----------	----1---------------------------
Ranunculaceae	11-1121-1-112111	12-2--1-2--------------1----------	1-----------1-------1-----------
Rosaceae	11-11231--1-1111	12212111111211221-21111-11----1---	--------------------------------
Orchidaceae	3321-2-11-1-13--	-1-1--1-13--11----2-2---2--3-512--	1-------------------------------
Juncaceae	31221312223-11-1	3321232211222-2231-1-21-22--------	-1--1-111----11-----1-----1-----
Thymelaeaceae	111-2-----12-121	------1-1---12----1-2--11---11----	1--1-----1----1-----------------
Cyperaceae	2122131-2-4-2--1	3531241221213-1112-1--1-------1---	----1-1------1----1-11---1---11-
Fabaceae	223-221---63-332	35-221427423222-2333212423113-23-1	2---2111--121--111-1-1----122---
Geraniaceae	11-1112211111211	21-21222212122212-111-2111-121-21-	11-211---111---1--1--11-11--11--
Myrtaceae	4442363323513333	4443522312424123132113125211111411	23123131211212123111111211111121
Rubiaceae	1-111-111111-111	1111-111111-111-1-111111111-1--1--	1--1-11----111---21--1-1----1--1
Lomandraceae	2211221-11312221	22131311322221312222111221123213-1	12-22111112221112-121-1---2-----
Phormiaceae	365444-132643544	36232543534542444342324444-4353341	23-45532443411214112212-12322-3-
Apiaceae	1111-23212413311	14112311211131232111211-1111232111	2--1-2112122--1121-1-2112-1111--
Lamiaceae	-----1---------1	-1-1------11-------------------1--	------2-----1--------1----------
Plantaginaceae	1--1-11111111121	-11111111-111-11111111111-1-111-11	11--221-11-1--1--1--12-111--1111
Pittosporaceae	-11--1--------1-	--------1-------------------1-----	-----1-----1----1----------1--1-
Campanulaceae	---12--12-222212	11-2111122-1111122311212221211131-	1111211211231-211211-21121113121
Poaceae	6285745777856577	8875675676777386775856778777867797	88889687889975978777756675895687
Mimosaceae	1-111----111-1-1	11-11-1211--1221-1-2-------22111--	12-132--21113-112-111-1-1-13---1
Asteraceae	466777445-767457	6814434587774474446355747764773673	73377777748777678778687796458898
Goodeniaceae	1111----1--1-1-1	12-----1112-1-1-112111111211121111	11112231222221122111-22131--2211
Crassulaceae	-----11------1--	11--2------11--31---------1----1--	-----1111-11-1-1--11-11112--111-
Malvaceae	----------------	----------------------1--11-11-11-	-11112111122-11121121211111-21-2
Chenopodiaceae	--1-------------	-11--1-1----1--12-11---11-2111-112	-2423123225234567626545644435535
Myoporaceae	----------------	----------------------------1-11--	-1-21121--2221212--2211-1-2211-1
Amaranthaceae	----------------	----------------------------------	---1--1---1----122-1-1------1--2
Brassicaceae	----------------	----------------------------------	----------1--------1---1111122--

gaudichaudii and the exotics *Anthoxanthum odoratum*, *Holcus lanatus* and *Myosotis discolor*) appeared to be characteristic of Yellow Box – Red Gum Woodlands beyond the main eastern limits of White Box. Only the western edge of the Tablelands were sampled in this study, however, and a more extensive survey is likely to reveal further species that distinguish the Tablelands woodlands from Slopes woodlands.

Many species showed a gradual decline in frequency from the Tablelands to the Slopes. These included the native perennials *Burchardia umbellata*, *Gonocarpus tetragynus*, *Daviesia genistifolia* and *Austrodanthonia pilosa* (infrequently recorded in White Box country); *Ranunculus lappaceus*, *Microlaena stipoides*, *Thysanotus tuberosus*, *Schoenus apogon*, *Hypericum gramineum*, *Cryptandra amara*, *Ranunculus pachycarpus* and *Drosera peltata* (absent from or infrequent in the more western White Box remnants); and the exotics *Acetosella vulgaris* and *Dactylis glomerata*.

Several species (e.g. the native shrubs and subshrub *Indigofera adesmiifolia*, *Acacia decora* and *Templetonia stenophylla*, and the exotics *Geranium molle* and *Orobanche minor*) appeared characteristic of White and Yellow Box woodlands on the Slopes, and were absent or declined both to the east and west.

More commonly, however, species frequent in White and Yellow Box woodlands of the Slopes but infrequent in more eastern woodlands continued into western woodlands. These included the small tree *Brachychiton populneus*, the native daisy *Vittadinia gracilis*, the native grasses *Austrodanthonia auriculata*, *Aristida behriana* and *Austrostipa nodosa*, and the exotics *Carthamus lanatus* and *Hordeum leporinum* (equally abundant across White, Grey and Bimble Box woodlands). *Callitris glaucophylla*, a common overstorey tree, as well as the native forbs *Sida corrugata* and *Calotis lappulacea* and the native shrub *Maireana microphylla*, occurred in White and Yellow Box woodlands but increased in western woodlands.

Species contributing to the grade from Grey Box (Eucalyptus microcarpa) *to Bimble Box* (Eucalyptus populnea) *woodlands*

The dominant grasses (*Enteropogon ramosus/acicularis*, *Austrostipa scabra* and *Austrodanthonia* spp.) did not vary significantly across the range of Grey and Bimble Box woodlands sampled in this study, but there was a grade in subsidiary species (Table 4). A number of subsidiary species were common in Grey Box woodlands but were absent or infrequent in Bimble Box woodlands. Few of these

Table 4. Two-way table indicating changes in floristic composition from Grey Box (*Eucalyptus microcarpa*) to Bimble Box (*Eucalyptus populnea*) woodlands. Sites are arranged according to the vector for overstorey eucalypts (GW=mixed Grey and White Box, G=Grey Box, GP=mixed Grey and Bimble Box, P=Bimble Box), and species according to their weighted average location along this vector. All species occurring in more than 14 sites are included, as well as selected others.

	GGGGGGGGGGGGGGGGGG	PPGGPPPGPPPPG
	W W WP P PP	P P
Geranium retrorsum	22-2--1---2--2-----	-------------
*Trifolium angustifolium**	2-3-2-----2---2----	-------------
Goodenia hederacea	11----3----1---2---	-------------
*Romulea rosea**	-2-31-----2--3----1	-------------
Juncus subg. genuini	2--1--2221--1--2---	-1-----------
Sclerolaena muricata	--1-2---2-----1--1-	-------------
Plantago varia	22-221-2----13-----	---------2---
Glycine tabacina	2---12-2------1----	-1------1----
*Patrorhagia nanteuilii**	2----21--21-----1--	2------------
Aristida ramosa	3---1--3---2-3-----	21-----------
*Trifolium campestre**	2--4-12---3-1--2-2-	2------------
Steckhousia monogyna	32-2--2---2-23--1--	2-2----------
*Chondrilla juncea**	21-1-1-1---1----2-1	----------1--
Poa sieberiana	44-2--31-22342----1	3-3---------1
*Medicago truncatula**	--3-2---2-----12-2-	-----1-------
Vittadinia gracilis	2--2---2-21----12-2	---1---------
*Bromus diandrus**	33-31-32--2-2222223	1--2---------
Austrodanthonia bipartita/fulva	-2-2--2--2-222-----	-2------1----
Themeda australis	5--3--2----323-----	--2-----3----
Dianella revoluta	42-3-23--3-4-3-1--1	-22-----4----
Lomandra multiflora	2--2--2--21222----2	1-1--1-------
Eucalyptus microcarpa	2533343135333343133	--23---2----3
*Aira alegantissima**	4--3-132--322---1-2	2-22-3-------
*Trifolium arvense**	2--2-2222-2-1-3-2-2	2-1--2-----1-
Dodonea viscosa	-32-123--3-443--1--	222----13----
Tricoryne elatior	31-2-222--2----12-2	212--2-----1-
*Avena fatua/barbata**	433322231-3-322-3-3	32332-22-----
Lomandra filiformis	32-1-3211-22--121-2	2122-2-2-----
Convolvulus erubescens	2-2121----3-1-11111	-1211------2-
*Vulpia bromoides**	522334--2-324-234-4	4----421-22-2
Bulbine bulbosa	32-2-2-2--1-23442-2	2121-22-11---
Vittadinia cuneata	2-1-3-332-1-2-2231-	----1-2--1-22
Maireana microphylla	--1-3--123--1-12-11	1--421-------
Austrodanthonia setacea/spp.	-324-3225----352-2-	2--4-2-3--2-4
Elymus scaber	223-3223312-3222223	2-2-2221223-2
Austrodanthonia caespitosa	22525-342-4-3--4334	3-2-333--3322
Austrodanthonia euriculata	12-3--34--4-3-125-4	3-22-322----2
Oxalis perennans	213222222-2--122112	2232--221222-
*Lolium spp.**	32332445341-2-33343	43425222-32-4
Austrostipa bigeniculata	122-1-2---3-3--22-3	4-5--3-4-----
Goodenia pinnatifida	-22233213-212222-3-	1-222-22-2222
Sida corrugata	-1122112212-1-22222	3-22-12--122-
Aristida behriana	---2--22--3-2-222-2	221--32-----1
Wahlenbergia luteola	22-2122----222222-1	222--22--1-23
Eremophila debilis	---1-12113111-1---2	2222-21-11---
Austrostipa scabra	3434344224434343344	3344-45344442
Enteropogon ramosus/aciculens	-3452244235-4332423	3443533233223
*Sonchus oleraceus**	-2-1-1121----2----1	322-21112----
Dianella longifolia	22---222-12-3-----1	222-2-2-31-21
Callitris glaucophylla	22-11253-35343-22-2	5-5--52143133
*Hypochaeris radicata**	31-2-2222-3-122222-	3-3223222222-
Einadia nutans	13-12122132-2--2223	32-2223-32212
Calotis cuneifolia	--2-223212-343-3--2	3-32-22-33323
*Echium plantagineum**	1-121121121--233222	2332212212212
Cheilanthes sieberi	31-2--21-22222212-2	2222-22222223
*Bromus molliformis**	---2---1-32---2-122	1-12-----22-2
*Hordeum leporinum**	--221---2----2--231	1-2-2--1-22-2
Chenopodium desertorum	-2222----2112---212	2222-22-41222
Calotis lappulacea	2--221--22-3--23---	-3-2--2223323
Daucus glochidiatus	----12----1-2122-22	3132-33-2222-
Triptilodiscus pygmaeus	----2-11----1-322-2	4-32-321-2122
Crassula sieberiana	-----2-11-----2212-	2-231331-322-
Thyridolepis mitchelliana	----------2-------1	122--3--1--1-
Plantago turrifera	--2------1-----2-1-	--1-1-2--2221
Maireana humillima	--------------3--2-	2--2-12--112-
Sida cunninghamii	-----1------------2	1-1-11-2-1-1-
Eucalyptus populnea	-------4--1-----23-	342-333-23413
Aristida benthamii var benthamii	---1-----------3---	---2--23---21
Stuartina muelleri	-----1--------12---	1----211--122
Hyalosperma semisterile	-------1--1-------2	2-2--33--213-
Sclerolaena bicornis	--2---------2---2-2	---21--2-3323
Erodium crinitum	-----1----1-----1--	1-222-12-213-
Goodenia cycloptera	----------------1-2	2-22-22--212-
Calandrinia eremaea	------1----------2-	2--1-22--1221
Brachycome lineariloba	-----------------1-	----2-2---2--
*Medicago laciniata**	--------1--------3-	-4-14-2223331
*Sisymbrium orientale**	----------------1-1	2-1--2---1222
Actinobole uliginosum	------------------1	1---22--122-
Menkea australis	-----------------1-	----2-2---22-
Calotis hispidula	----------------12-	---1-122--223
Isoetopsis graminifolia	-----------------1-	------11-2-21

Table 5. Two-way table indicating changes in floristic composition in relation to landuse in eastern woodlands. Sites are arranged according to the landuse vector, and species according to their weighted average location along this vector. T=TSR, R=roadside, C=cemetery; *denotes introduced species. All species showing notable trends are included, as well as selected others.

	TTTTTTTTTTTTTTTTTTTTTTTTTR	CCCCCCCCCCCCCCCCCC
Mairaana microphylla	1---2----11---------------	------------------
*Geranium molle**	243--31--3-35-------1---2-	------------------
Aphanes australiana	122------1-121------11----	------------------
*Hordeum leporinum**	2-233211-2--3----2-2------	--1---------------
*Medicago lupulina**	22222333----32-33--2----3-	-------------1----
*Poa bulbosa**	322222---22121---1-3--2---	-1-2--------------
*Moenchia erecta**	322--22---113--2-112---11-	---1---------1----
*Carduus tenuiflorus**	--2--1-12-123--32---------	------------------
*Parantucellia latifolia**	3222-323-3223112---122--1-	-2-1--------------
*Arctotheca calendula**	3232123--3232--212-2-1----	-2--------11------
*Sherardia arvensis**	23322332243232-3223232--3-	----1-------------
Crassula sieberiana	-22-1----1--21------1-1---	-----------1------
Austrodanthonia auriculata	1332-23-2-----3-1---2----1	--2---------2-----
*Linaria pelisseriana**	-32---1-----1------1-2-1--	-----------1------
*Cynosurus echinatus**	1-2--23-222-2--21222----1-	--------------1---
*Echium plantagineum**	53233331243232221211------	1-1---2-----11-1--1
Bothriochloa macra	132--3323-112-22-42-3-3---	---2--------------
*Romulea rosea**	4-2423-232533--2-33-1-----	---2------22------
*Cerastium glomeratum**	322-22-1-33231-3-2-222-21-	--1--1-----1-----1
Dichondra repens	--------2122-122---------2	------------------
*Carthamus lanatus**	21---2--12--2-23---------1	---------2---1----
*Trifolium subterraneum**	31332322333332-322-32-3---	3-231----1----1--1-
Aristida ramosa	-2-13-3-3223---2-2-21-41--	-2-----2----------
*Myosotis discolor**	--2----2----12--2--2-2-1--	2-----------------
Austrodanthonia caespitosa	--3-2---3--2--4---2------1	---22-------------
*Hypericum perforatum**	2-12-32222222----2323-111-	1---2-----2-11----
Solenogyne dominii	--31-1312---2--2----11--2-	-2-2------2-------
Arthropodium minus	-321-11-23-23-22---2222-32	-1------2--1--1---
Wurmbea dioica	11-1221-----2------213322-	---11-----------1--
*Rosa rubiginosa**	11-2-211111211-1-211-----1	------1-2-------2--
Carex inversa	111--33--13231-3-212222-11	2-----1-2--------2-
Triptilodiscus pygmaeus	133-2-31121-2--2---3-2-21-	12-11--2--21--1---
Oxalis perennans	-221-12-232331122222222222	122222--1---------
Eucalyptus blakelyi	3353-2433-2-33-3423443331-	33-33-----221-2--3-
Plantago lanceolata	4--32412434222-223414-----	21-34-2-1-3-1--21--
Daucus glochidiatus	-22-2------221---2-323--22	-----2--21---------
*Lolium spp.**	23254322232343543432323-24	222-232222--21--2-1
Austrodanthonia setacea/spp.	-2-32-33-32-33-42-2-42223-	232--4--22--------
Drosera peltata	122--231--2-3--22--3-322--	33--3-----12--2---
Austrostipa scabra	-222222-32113-3322222-22-3	-22--3231---2---1--
Eucalyptus melliodora	2-5332--3------52-3433-2--	12321-1---22---22--
*Vulpia bromoides**	2324423344223-23324-413-2-	3-2353--1-223123---
*Salvia verbanacea**	311223--34222--2-31-3----1	--22-212-2---2----4
*Bromus diandrus**	5223-41-54345-253343223213	3-3--123212-21-2-42
Rumex brownii	232222222121311222121-2--1	2-22----2-21-2-2221
*Bromus molliformis**	42342533544241233433322122	2-43232-22--2113223
*Anagallis arvensis**	2-2-222-12222-232322223212	-2----22-2-221----2
*Briza minor**	3323-3323332312432-3333222	32223-2-1122-13212--
Eucalyptus albens	4433-43--5545-42-5--4-5-55	-----53351--313--13
Lomandra filiformis	2223222-2233212322223233323	232--22-2123222-2-1
Plantago varia	122212-2-4332323-33322321-	--22233-32-323---1-
Acaena agnipila	22232322222221-1-332222112	--232-2-22221-2-222
Goodenia pinnatifida	---3322-23-11-13-32-1----2	1-2222-212-122-----
*Aira elegantissima**	3543-333242232-332-3343322	333341131235323-32-
Convolvulus erubescens	1122-22-22232232-3322---22	1-32-22233-122-11-2
*Trifolium campestre**	2323433-333332333323343-13	3332332433223222222
Hydrocotyle laxiflora	2211-121222-31231332323233	2223-23331-2-22--22
Dichopogon fimbriatus	22-3--3214412--3-2321-1--2	--23-3-342-123-212-
Hypericum gramineum	--2--1--1-1-2--21-2312--2-	12--2-2-2-2---21---
*Trifolium ervanse**	23224-2-133223121--2233-3-	2232221423-42312222
Bulbine bulbosa	1221-121143-232242132-4-11	3-2-33223215-332232
Eryngium rostratum	----------1-1---1--2------	----1------1---21--
Lomandra multiflora	------1--1222--2-11112211-	---211121-23221221-
Leptorhynchos squamatus	------212-2-22-1--1312--2-	223333222-43-2223--
Poe sieberiana	----23-3-32322323423223225	235444445533554[illegible]45
Stackhousia monogyna	--1-1-2-12211------2-2----	2-22--112224-32[illegible]
Themada australis	--1--44--3333-2231422234-	5555535535555555[illegible]
Chrysocephalum apiculatum	----21-1-3--21-2-3-3321-2-	222314-332223333422
Dianella longifolia	--------212-2---12-2122-11	2132222332232222122
Microseris lanceolata	-11---1-----2--1---2-2222-	--33242-33-42421-22
Craspedia variabilis	------2-----1-------------	--133-----3---2-2--
Dichelachne micrantha	----------1-2-13--------1-	-2-2-3--323--3--22-
Thysanotus tuberosus	---------------1---1---2--	1---------12-22----
Linum marginale	----2-----11------1-2-----	---2-22232-221-11--
Ranunculus lappaceus	--------------2-------3-2--	2--23-3-3-2-1--221-
Dianella revoluta	----------1-1----222-232--	-3-22332423-3433333
*Tragopogon porrifolius**	-------------------2------1	---1--2-3-2-2----1-
*Varbascum virgatum**	-----------2--------------	--2--1--11---2--211
Daviesia genistifolia	---------------------1-----	-2------1-2-----3--
Plantago gaudichaudii	-----------------1--------	1--------------13--
Pimelea curviflora	-------------------11--1--	-2-2-3--31221321221
*Lactuca serriola**	--------------------1-----	-----12-11---1--1-2
Cryptandra amara	--------------------------	--122-----3---23312
Templetonia stenophylla	--------------------------	------2--1-1-1---11
Chrysocephalum semipapposum	--------------------------	-------114--4---2-3
Pimelea glauca	--------------------------	---------21----33-3

(potentially the native *Sclerolaena muricata*) were characteristic of Grey Box woodlands. Most were species that were abundant in eastern woodlands and continued into Grey Box but were uncommon in Bimble Box woodlands (e.g. *Geranium retrorsum*, *Goodenia hederacea*, *Juncus* subg. *genuini*, *Plantago varia* and *Stackhousia monogyna*). Similarly, the grasses *Themeda australis* and *Poa sieberiana* were frequent in Grey Box remnants, but were recorded in only one Bimble Box site without Grey Box (at Trangie and Ungarie respectively).

A greater number of species was typical of the Bimble Box sites of this study. These included annual daisies such as *Isoetopsis graminifolia*, *Calotis hispidula*, *Actinobole uliginosum*, *Brachychome lineariloba* and *Hyalosperma semisterile*, a range of other native annuals (e.g. *Menkea australis*, *Calandrinea eremaea* and *Erodium crinitum*) and native perennials (e.g. *Goodenia cycloptera*, *Maireana humillima* and *Thyridolepis mitchelliana*), and the exotic species *Sisymbrium orientale* and *Medicago laciniata*.

Trends related to landuse

The second major trend on the ordination was related to Landuse (Table 1, Fig. 2f). Across the whole of the east–west gradient, cemetery remnants were usually distinct from roadside and TSR remnants. This trend was most prominent for eastern sites (Fig. 2f), and for these sites was also apparent (with some exceptions) on the UPGMA cluster analysis (Fig. 3c). In Grey and Bimble Box sites the distinction became more blurred, with some mixing of roadsides and TSRs with cemetery remnants on the ordination (Fig. 4b), and poor distinction of cemeteries and TSRs on the cluster analysis (Fig. 3c).

Species involved in distinguishing the landuse classes varied according to position on the east–west gradient, so are best described using the two-way tables derived from separate analyses of eastern and western woodlands (Tables 5, 6). As well, more general differences were apparent for relative shrub abundance and native annual abundance (Fig. 6, Table 1). While relative shrub abundance was generally low, it was often higher in cemeteries than TSRs (Fig. 6a). By contrast, native annuals were uncommon in cemeteries, but increased in TSRs, particularly in the west (Fig. 6c, Table 1). For example *Triptilodiscus pygmaeus* and *Daucus glochidiatus* were frequent in TSRs in the east (Table 5), but not in eastern cemeteries. Native annuals typical of western TSRs included the daisies *Brachychome* spp., *Rhodanthe corymbiflora* and *Stuartina muelleri*, and other forbs such as *Menkea australis*, *Bulbine semibarbata* and *Plantago turrifera* (Table 6).

In eastern woodlands, cemeteries were also distinguished by a markedly lower relative exotic species abundance (Fig. 6b), dominance by *Themeda australis* and/or *Poa sieberiana*, and a range of native species that were infrequent (e.g. *Pimelea glauca*, *Templetonia stenophylla*, *Chrysocephalum semipapposum*, *Cryptandra amara*, *Pimelea curviflora*,) or declined notably (e.g. *Dianella revoluta*, *Ranunculus lappaceus*, *Linum marginale*, *Dichelachne micrantha*, *Microseris lanceolata*, *Dianella longifolia* and *Chrysocephalum apiculatum*) in grazed sites (Table 5).

In eastern TSRs, the dominant grasses of cemeteries were replaced by a mixture of exotic species and native grasses such as *Bothriochloa macra*, *Aristida ramosa*, *Austrodanthonia* spp. and *Austrostipa scabra*. The latter three of these grasses were common in western woodlands, but it is of interest that *Bothriochloa macra*, highly abundant in grazed eastern woodlands, was common neither in western woodlands nor little-grazed eastern woodlands, raising an interesting question as to the original ecological range of this species in the region (Fig. 5c). A range of natives appeared to tolerate light grazing in TSRs (e.g. *Lomandra filiformis*, *Plantago varia*, *Acaena agnipila*, *Goodenia pinnatifida*, *Convolvulus erubescens*, *Hydrocotyle laxiflora*, *Dichopogon fimbriatus*, *Hypericum gramineum* and a number of others not shown) or benefit from it (e.g. *Wurmbea dioica*, *Arthropodium minus* and *Solenogyne dominii*), but a large number of exotic species also increased in TSRs (Table 5). Although they include a number of Yellow Box – Red Gum and tableland remnants, these results are generally concurrent with our earlier studies of grassy White Box woodlands (Prober & Thiele 1995, Prober 1996), and a more detailed discussion of these trends is given in those papers.

In western woodlands, no clear change in dominant native grasses was involved in the distinction between roadside, TSR and cemetery remnants (Table 6). *Enteropogon ramosus/acicularis Austrostipa scabra*, and *Austrodanthonia* species (especially *Austrodanthonia setacea* and *Austrodanthonia caespitosa*) were moderate to common at most sites (Fig. 5d-f). Their relative abundances varied from site to site, but one or a combination of these, most commonly *Austrostipa scabra*, were the general dominants in both cemeteries and TSRs.

There was, however, a pattern of declining diversity of grasses related to landuse (Fig. 4c). The diversity of native grasses in western cemeteries was remarkably high (mean 11.2, range 5–16), and was usually lower in grazed sites (mean 7.5, range 5–11). This reflected a decline in frequency or abundance of grasses such as *Themeda australis*, *Thyridolepis mitchelliana*, *Poa sieberiana* and *Austrodanthonia bipartita/fulva* (syn. *Austrodanthonia linkii*), and to a lesser extent, *Austrodanthonia auriculata* and *Austrostipa bigeniculata* (Table 6). As well there appeared to have been some change in the local distribution and structure of the grasses resulting from management (personal observation, Biddiscombe 1953). In cemeteries that appeared most natural (less invasion by dense *Callitris* regrowth, greater structural diversity, low exotic species abundance) the most common grass species often occurred as large tussocks in distinct clumps or patches (particularly for *Austrostipa scabra*, *Austrodanthonia* spp., *Themeda australis* and *Poa sieberiana*). These were interspersed with clumps of shrubs and patches of bare ground, and other natives were scattered sparsely or in small patches

Table 6. Two-way table indicating changes in floristic composition in relation to landuse in western woodlands.

Sites are arranged according to the landuse vector, and species according to their weighted average location along this vector. All species occurring in more than 14 sites are included, as well as selected others. T=TSR, R=roadside, C=cemetery; *denotes introduced species. *Enteropogon ramosus* and *Enteropogon acicularis* both occurred in the survey region.

	TTTTTRTTCTTTRCTR	CCTCCCCCCTCCCCCC
Sclerolaena muricata	1-212-1---------	----------------
Brachycome ciliaris	3-23-----2------	----------------
*Medicago truncatula**	3-222-1---2-----	---------1------
Brachycome lineariloba	-2-1---2----2---	----------------
Rhodanthe corymbiflora	3-143212----31--	4--------1------
Asperula cunninghamii	2-2121---2------	-----------3----
Menkea australis	-2-1---2----2---	2---------------
Meireana microphylla	12213-1-4-23---1	----1-1-11------
Atriplex semibaccata	-22222-1---21---	--1-112-------1-
Wahlenbergia communis	22-222-21---2-22	1------1---2----
Arthropodium minus	-11-213--32--2--	-1--------2-----
Carex inversa	-32--1-1---2-222	----------2-----
Wurmbea dioica	-1----2---2-12--	----------------
*Medicago laciniata**	-413-2-31---213-	3-4----------2--
Bulbine semibarbata	-2----12232--32-	----------------
Plantago turrifera	21-1---2--21212-	2----------1----
*Arctotheca calendula**	-223-231-13-23--	-----------2-1-2
*Hordeum leporinum**	222311-2-----22-	---2-21-1--2---2
Goodenia pinnetifida	22333222232-2221	22-22--21-22--12
Austrodanthonia setacea/spp.	2-52-352432--4-2	-3-4----222----3
Crassula sieberiana	-112-122322-3-31	2----1--23-2----
Vittadinia cuneata	11213-2---2-2213	2---23-1--3-2---
Lolium spp.*	3534223224342435	-233233142443---
Austrodanthonia caespitosa	53235--3--4-3234	22-2334433322---
Calotis lappulacea	--2-22232132233-	2-32--------223-
Convolvulus erubescens	21-12-1-111-----	2-111113---22---
Sida corrugata	1-222-2221212-12	21-212223112----
Elymus scaber	32323123-2212223	-2--3232222222-2
Oxalis perennans	3-212222222-2-22	2122-1222-2321-1
Eucalyptus microcarpa	3-33324-3435-3-1	-5-33133--322-33
Stuartina muelleri	-----111-12-12--	2-------12------
*Bromus molliformis**	---2--222--3-221	---2-1221--1----
*Echium plantagineum**	1212123221322221	1-32-221212311-2
Calandrinia eremaea	---2---21---211-	2-------221-----
Eucalyptus populnea	-3-3---4----3334	1-4--2-133-2-2--
Enteropogon ramosus/acicularis	4522223232233334	234544353344-3-3
Einadia nutans	-2122--221233222	13212232322-13--
Austrostipa scabra	3-24334444345242	4434434434443433
*Avena fatua/barbata**	321-222-32--2--3	-32333333-234--2
Triptilodiscus pygmaeus	----21312-2-2221	2---122-4313----
*Vulpia bromoides**	2-2-3122-43-222-	-2-3444344--5-2-
*Hypochaeris radicata**	-222-222222-2-22	21-212-3332332-2
Chenopodium desertorum	2--12--22--2221-	2222222122-2-41-
Daucus glochidiatus	---21-22222-3-2-	2-1-2-2133-3-2-1
Calotis cuneifolia	2-1-2--322322332	2---4-2-3233-333
Austrostipa bigeniculata	2---14----2-----	-2--323343251---
Lomandra filiformis	--1--21-232----1	-211-12222223-2-
*Trifolium arvense**	--2---3--2-----2	1--2122222212---
*Sonchus oleraceus**	-21--1---1--1--2	-221--1-3112-2-2
*Bromus diandrus**	---21-2-2-2----2	-3-322321-3-3--2
Eremophila debilis	--1---1-21-31-11	--211-212222-11-
Myoporum montanum	3----------2---1	--2-4-2-23---32-
Dianella longifolia	-2-------2-12112	222-3-122-2223--
Cheilanthes sieberi	-----2222-122321	2122222222223222
Austrodanthonia auriculata	-----21-2-2-22-4	-2-3354433321---
Bulbine bulbosa	------4-124-2-12	-212222122-231-3
Wahlenbergia luteola	----1-2--22-231-	2222221-22222-22
Aristida behriana	------2---2-21-2	--2222232321----
Dodonea viscosa	2---11---2-3----	-32-41--2-32-343
Dichondra repens	---------1---1-2	-21--21----2-2--
Xerochrysum bracteatum	-------3----3131	2----22-3223---2
Callitris glaucophylla	----11-1-2232333	32-1422555552433
Acacia deanii	-----2--2-2-2---	--1-2-3-2232-2-3
Senna artemisioides	-------1-2---32-	--2-22322--3-33-
Tricoryne elatior	---------21----2	1112-22222223---
Hydrocotyle laxiflora	---------12-1-12	-1---11-3--12--3
*Bromus rubens**	----------------	-2---22-21-1----
*Aira elegantissima**	--------21-----2	---3212323324-2-
Dichopogon fimbriatus	---------23----2	---22-2322232--3
Chrysocephalum semipapposum	------------1---	----122-122-----
Austrodanthonia bipartita/fulva	-----------2----	-2222-----2--122
Dianella revoluta	---------213----	-223--1---324443
Poa sieberiana	-----------2-1-1	-4-24-123-334-32
Thyridolepis mitchelliana	----------------	1-2---1213-2-1--
Brachychiton populneus	------------11--	1-1---1-1--12211
Aristida ramosa	----1----------3	--1-----2---3-23
Chrysocephalum apiculatum	-------------1-1	22-2---221333222
Lomandra multiflora	-----------2----	---22-2111212-22
Glycine clandestina	--------------1-	1----11--11121-1
Geranium retrorsum	----------------	-2-2---2--1-2--2
Stackhousia monogyna	----------------	-2-221-22-223--3
Pimelea curviflora	----------------	----2--2----1--1
Themeda australis	----------------	---32-----225333
Microseris lanceolata	----------------	-------1--32--3

throughout. This structure and patchiness was less apparent in grazed remnants and in cemeteries that were regularly mown, where a more continuous, low sward was formed.

A range of other subsidiary native species also contributed to the distinction between Grey and Bimble Box cemeteries (and less-disturbed TSRs) and grazed remnants (Table 6). A few of these, such as the abovementioned grasses *Thyridolepis mitchelliana*, *Austrodanthonia bipartita/fulva*, and the shrub *Senna artemisioides* were frequent only in Grey and/or Bimble Box woodlands. Others, such as *Themeda australis*, *Poa sieberiana*, *Dianella revoluta* and *Chrysocephalum semipapposum*, were the same as species distinguishing little grazed sites in eastern woodlands, although the two grasses rarely dominated western sites and all were generally more robust in the east. A third prominent group contained common eastern species that showed greater tolerance of grazing in eastern woodlands, but were largely restricted to cemeteries in the west. These included the perennial forbs *Stackhousia monogyna*, *Geranium retrorsum*, *Glycine clandestina*, *Lomandra multiflora*, *Chrysocephalum apiculatum*, *Dichopogon fimbriatus* and *Tricoryne elatior*.

Other native species of western woodlands were more typical of grazed Bimble and Grey Box sites than cemeteries. These were mostly species that were not found elsewhere in our sampling i.e. were infrequent in eastern woodlands, and included the annuals noted above and perennials such as *Sclerolaena muricata* and *Asperula cunninghamii*.

By contrast with the eastern woodlands, relative exotic species abundance was not notably higher in the TSRs and roadsides surveyed than in cemeteries in western woodlands (Fig. 4d), rather was generally lower than eastern woodlands (Fig. 6b). This result is likely to have been partly influenced by our sampling strategy — in the west there were fewer discrete TSRs available and thus our sampling was biased towards smaller, less weedy sections of Travelling Stock Routes (Fig. 2g); high exotic species abundance is still common in poorer remnants of Grey and Bimble Box woodlands (personal observation). Nevertheless it does indicate that at least some TSRs in western woodlands have relatively low exotic species abundance, and points to a need for greater survey effort in western TSRs.

Exotic species composition showed some trends related to landuse. Some exotic species were more typical of cemeteries e.g. *Aira elegantissima* and *Bromus rubens*, and others more typical of TSRs e.g. *Medicago truncatula*, *Arctotheca calendula* and *Medicago laciniata*. Most, however, occurred relatively evenly across landuse classes. Some of these were moderately abundant at many sites (*Lolium* spp., *Avena fatua*, *Vulpia bromoides*), while others were frequent but usually uncommon (e.g. *Hordeum leporinum*, *Bromus molliformis*, *Echium plantagineum*, *Medicago minima*, *Hypochaeris radicata*).

Finally, a number of interactions were notable between the landuse and the east–west gradients. As noted earlier, a number of native species that were frequent across both landuse classes in the east were found only in cemeteries in the west. The reverse generally did not occur (i.e. few species were ubiquitous in the west but limited to cemeteries in the east.) As well, few species that were ubiquitous in the east were restricted to TSRs in the west.

However, some species that were common across landuse classes in the west were favoured in TSRs in the east — these included some of the more prominent grass species (e.g. *Austrodanthonia auriculata*, *Austrodanthonia setacea*, *Austrostipa bigeniculata*, *Austrostipa scabra*), the native annuals *Triptilodiscus pygmaeus* and *Daucus glochidiatus*, the native perennials *Maireana microphylla*, *Dichondra repens* and *Crassula sieberiana*, and exotic annuals such as *Hordeum leporinum* and *Lepidium africanum*.

These trends suggest that typically eastern species become more susceptible to grazing under drier conditions, and conversely, that some western species are better able to compete in the east when the natural dominants are diminished by grazing. Consequently, we suggest that grazed sites have a more western character, and indeed, five TSR samples that were in close proximity to cemetery samples invariably fell further to the right ('west') on the ordination than the respective cemetery remnants (not shown).

Other trends in the floristic data

Environmental variables

The only other major environmental trend in the floristic data was related to latitude. The correlation with latitude was relatively low for the full and eastern data sets (Table 1), but nevertheless is likely to represent part of a north–south climatic grade as described for grassy White Box woodlands in an earlier study (Prober 1996). A higher correlation with latitude was obtained for the western data subset, equal in magnitude to that observed for the east–west trends within these western woodlands (Table 1). The relationship with latitude is likely to have increased in western woodland sites because a wider latitudinal range was sampled (owing to low availability of little-disturbed cemetery remnants). As well, there was some confounding of latitude with distance inland for western woodlands, as Bimble Box does not occur as far south as Grey Box.

Vector correlations of the ordination with the variables tree clearing and soil resource class were marginally significant in the full data set (only), but were generally very low. High levels of tree clearing were more common in cemetery remnants, especially in the east, thus tree clearing may have made some contribution to the differences in understorey between cemeteries, roadsides and TSRs.

Soil resource class generally varied only from 'arable' to 'suitable for grazing' in the set of sites in the present study, and the slight correlation of this variable with the ordination of the full data set can be attributed to the relative increase in arable sites on the alluvial soils in the west, and decrease in arable sites on the tablelands. Soil resource class was noted as an important determinant of understorey in grassy White Box woodlands in an earlier study that sampled a broader range of soil resource classes (Prober 1996), but sampling remnants with shallow or infertile soils was beyond the scope of the present study.

Influence of plot size

Correlation of plot size with the ordination of the full data set (Table 1) was low and showed no consistent relationship with the east–west or landuse gradients (Fig. 2g), indicating a minimal influence of this variable on analyses of this data set. In the two data subsets, the relationships between plot size and the ordinations were stronger (Table 1) and somewhat related to landuse (Fig. 2g), suggesting that landuse trends described for these ordinations were potentially influenced by plot size. This is highly unlikely, however, because the relationships between plot size and landuse were reversed for the different data sets, with TSR samples on average larger than cemetery samples in the eastern data subset, and cemetery samples often larger than TSR samples in the western data subset (Fig. 2g). Despite this reversal, eastern TSRs grouped with western TSRs in the main analysis, indicating greater influence of environmental factors.

Further indication that plot size did not significantly influence the environmental trends described is the lack of significant correlations between native species richness and plot size in all data sets (r=0.17, 0.20 and 0.35 for the full, eastern and western datasets respectively). Likewise, correlation of native richness with the ordinations was not significant for the full and eastern datasets (Table 1, Fig. 2h). Correlation with the ordination of the western dataset was significant but did not reflect patterns in plot size (vectors of maximum correlation for native richness and plot size were 72° apart).

Discussion

Natural floristic patterns in grassy box woodlands

Understorey composition varied considerably across the east–west gradient sampled, with a notable change in the natural dominant grasses from *Themeda australis* and *Poa sieberiana* to *Austrostipa scabra*, *Enteropogon ramosus*/*acicularis* and *Austrodanthonia* spp., and with few species occurring consistently across the whole gradient (approximately 10% of natives and 10% of exotic species, Table 2). This contrasts with patterns recorded across the north–south extent of Grassy White Box Woodlands in NSW, where the dominant grasses of little-disturbed sites (*Themeda australis* and *Poa sieberiana*) varied little, and only around 50% of subsidiary species varied with the gradient (Prober 1996), despite a much wider geographical range (900 km cf. 400 km in this study).

With some important exceptions, dominant overstorey eucalypts were good indicators of natural understorey composition. The change from eastern woodlands (Yellow Box, White Box or Red Gum) to western woodlands (Grey or Bimble Box) was concurrent with the change in dominant grasses, and associated with notable changes in subsidiary native species, including an increase in the diversity and abundance of native annuals, species of the families Chenopodiaceae, Myoporaceae, Malvaceae, Brassicaceae and Amaranthaceae, and changes in the main genera of shrubs and daisies. As described by Moore (1970), the change from eastern to western woodlands occurs approximately at the 500 mm rainfall isohyet, and is likely to be determined by edaphic as well as climatic factors. This distinction is largely consistent with other studies (C. Moore 1953a, R. Moore 1970, 1993, Beadle 1981, Keith 2002), although Austin et al. (2000) grouped White Box with Grey Box over significant areas of woodland within the Central Lachlan region.

Working in the western division of NSW, Beadle (1948) similarly stressed the relationship of Grey Box and Bimble Box–White Pine (*Callitris glaucophylla*) associations with the Red-Brown Earths (the typical soils of the alluvial parent materials in this study). He suggested, however, that the pre-European herbaceous stratum in these woodlands was sparse, and that clearing of timber had led to rapid migration of native species from both the east (e.g. *Austrostipa scabra*) and the west (Asteraceae).

We cannot conclusively refute this claim, as most remnants of this study had been disturbed to some degree through grazing, tree thinning and/or mowing, and there is observational evidence that dense overstorey can reduce the density of the herbaceous layer (personal observation). However, as previously noted, species such as *Austrostipa scabra* were more characteristic of western woodlands of this study than of little-grazed eastern woodlands, so it is likely that this was naturally the case. As well, some of the western cemeteries were well wooded, but still showed a high diversity of understorey species. Even for cemeteries with a sparser overstorey, it is not parsimonious to assume that grazing-sensitive eastern species had migrated long distances to these small sites after they were cleared. We suggest instead that the density of the eucalypt canopy was originally variable, allowing patches of denser understorey where the canopy was more open. We interpret the patterns of understorey composition in western woodlands as consistent with a naturally more westerly distribution of many 'eastern' species before the influence of grazing, as suggested by Moore (1970), and an increase in or influx of some (particularly annual) native species, potentially from further west, under grazing.

The occurrence of the other major overstorey tree species recorded in this study, *Callitris glaucophylla*, did not concur with the distinction between eastern and western woodlands (Table 2). Rather, it became frequent in the western parts of the White Box woodlands and continued through to Bimble Box woodlands, concurrent with the grade in understorey species. Beadle (1948) noted that this species is found over a wide range of climatic and soil conditions, but is confined to soils of a sandy nature. Our sampling was insufficient to determine whether any understorey patterns can be specifically related to *Callitris glaucophylla* or its relationship with sands.

Eastern box woodlands

Changes in understorey within eastern and western woodlands were less distinct than changes between these woodlands. In eastern woodlands, the relationship between understorey and overstorey composition was complicated by the occurrence of Yellow Box and Red Gum across the grade. The understorey of Yellow Box/Red Gum remnants reflected their position on the east–west gradient, grouping more closely with White Box remnants when on the Western Slopes, and becoming more distinct when occurring beyond the main eastern limit of White Box. Thus, for the eastern woodlands included in this study, the regional presence or absence of White Box provided a better indicator of understorey composition than the locally dominant eucalypt.

This is consistent with other studies (Moore 1953a, Keith 2002) that treated White and Yellow Box woodlands of the Slopes as a single unit, and recognized a separate community for the Yellow Box of the Tablelands. The use of botanical region or bioregion is a practical means of separating these groups (Fig 2e), although some sites in the eastern parts of the slopes region were beyond the main distribution of White Box and could be grouped with Tablelands woodlands. Some White Box communities are also known from the Central Tablelands, and it remains to be tested whether the understorey of these are more closely related to other woodlands on the Tablelands, or to White Box woodlands on the Slopes.

Other studies have used different or finer groupings within White and Yellow Box woodlands of the Tablelands and Slopes regions. Moore (1970), Beadle (1981) and Bower and Semple (1993) considered Yellow Box woodlands on the Slopes separately from White Box woodlands, grouping them with Yellow Box woodlands on the Tablelands. For the Central Lachlan region, Austin et al. (2000) included White Box in four major alliances, broadly consistent with a grade from east to west, according to their co-occurrence with combinations of Apple Box, Red Gum, Yellow Box, Grey Box and *Callitris glaucophylla*. For the southern tablelands and adjoinging eastern fringe of the western slopes, Thomas et al. (2000) recognized a number of variants of White Box, Yellow Box and/or Red Gum woodlands based on existing floristic composition, including a broad distinction between those in south-west of the region from those to the north and east.

Western box woodlands

Our sampling of western woodlands was not adequate for detecting the likely range of variation within them, for example Austin et al. (2000) recognized a Yellow Box/Grey

Box community as distinct from other Grey Box communities. Nevertheless, our data suggest that the change from Grey to Bimble Box parallels a grade in understorey composition associated with an increase in a range of chenopods, annual daisies and other natives, and the loss of a range of species more typical of eastern woodlands (although sites with mixed overstorey fell anywhere along this gradient, Fig. 4a). This is consistent with the general distinction made between Bimble and Grey Box woodlands made by earlier workers (e.g. Beadle 1948, Moore et al. 1970, Beadle 1981. Austin et al. 2000), although differs from the approach of Sivertsen & Metcalfe (1995) for the Forbes–Cargelligo region, where they made no major distinction between Grey and Bimble Box woodlands.

More generally, Bimble Box woodlands have been treated in greater detail across their range by other workers (Beadle 1948, Biddiscombe 1953, Beeston et al. 1980), who have described a wide range of both shrubby and grassy Bimble Box communities across a range of soil types. Comprehensive studies of understorey patterns within Grey Box communities, however, are still lacking.

Management issues

The change in dominant grasses from eastern to western woodlands has important management implications. In little-disturbed grasslands and grassy woodlands of more productive regions of south-eastern Australia, burning and slashing are considered important management tools for encouraging the dominance of *Themeda australis* while also maintaining high species richness (Lunt & Morgan 2001). Burning and slashing are likely to be less important for remnants dominated by other grasses, although they could be used to influence the relative dominance of different grasses. For example, based on observations in railway exclosures in Bimble Box woodlands, Biddiscombe (1953) suggested that annual burning at the beginning of summer favoured the persistence of *Themeda australis* while suppressing *Austrostipa scabra* and *Paspalidium gracile*. As aboriginal burning regimes in these woodlands are poorly known, it remains unclear whether *Themeda australis* was more abundant throughout them before European settlement.

The floristic composition and abundance of native shrubs in pre-European woodlands is of particular significance for woodland restoration. Shrubs can provide important fauna habitat, e.g. as cover for a range of bird species (Seddon et al. 2001), and dense shrub plantings are often promoted across the woodland regions. On the other hand, dense plantings of shrubs in areas where they were originally sparse are of questionable value for the conservation of the original ecological community and may disadvantage some herbaceous species and associated fauna. Although our data were limited by lack of completely undisturbed remnants, some patterns in shrub species composition and abundance were apparent across the range of woodlands sampled. As observed by earlier workers (e.g. Moore 1953a), shrub abundance was generally low, but was higher in cemeteries than TSRs, and was quite high in two western cemeteries that had been cleared of trees (Fig. 6a). Medium and large shrubs (e.g. *Senna artemisioides* and *Myoporum montanum*) were naturally more abundant in western woodlands than in the east, consistent with the observation of Beadle (1948) that shrubs commonly form a prominent stratum in Grey Box woodlands north of Narrandera. Small to medium shrubs (e.g. *Cryptandra amara*, epacrids) were more abundant on the tablelands than in White and Yellow Box woodlands of the western slopes, where shrub abundance was particularly low.

A significant difference in understorey composition between cemetery and TSR/roadside remnants, probably reflecting effects of intermittent grazing by livestock, was evident across the range of Box woodlands studied. However, the distinction was weaker in the west, and some of the species involved were different for eastern and western woodlands. As discussed in more detail in Prober & Thiele (1995), grazing in eastern woodlands has led to changes in the dominant grasses, decline in a range of natives, and a significant increase in exotic species abundance.

In western woodlands, a suite of native species were less frequent in TSRs and, consistent with observations by Beadle (1948), there was an increase in native annuals and unpalatable species such as *Maireana microphylla* in grazed sites. However, for the western woodlands surveyed, there was no notable increase in exotic species abundance in the lightly grazed remnants surveyed, and no obvious change in the dominant grasses. Regarding the latter, Biddiscombe (1953) described increasing dominance of *Austrostipa scabra* under light grazing, and increasing *Enteropogon ramosus/ acicularis* then *Chloris truncata* under heavier grazing pressures. These effects were not evident from our data, but an increase in *Austrostipa scabra* and *Enteropogon ramosus/ acicularis* is consistent with the loss of the more diverse combination of grasses found in cemeteries. For example, *Poa sieberiana*, originally a dominant of eastern woodlands, was remarkably frequent in cemetery remnants of western woodlands (recorded in 12 of 16), and was notably absent from grazed sites. This is consistent with Moore (1959), who noted that *Themeda australis* and *Poa sieberiana* were originally prominent in these woodlands. We recorded *Chloris truncata* in only five sites, at low abundance, perhaps reflecting the lack of heavily grazed sites in our survey.

Finally, it remains unclear whether the reduced distinction between cemeteries and TSRs in western woodlands indicates that the western cemeteries are more disturbed than eastern cemeteries (e.g. through rabbit grazing; high levels of dense *Callitris* regrowth were also observed in many western cemeteries), that some western TSRs have been less affected by grazing than eastern TSRs, or perhaps most likely, a combination of the two. A more extensive rangewide study of native understorey in these woodlands, particularly those dominated by Grey Box, would be valuable.

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References

AUSLIG (1990a) *Atlas of Australian resources* Third Series, Volume 6, *Vegetation* (Australian Surveying and Land Information Group: Canberra).

AUSLIG (1990b) *Atlas of Australian resources* Third Series, Volume 4, *Climate* (Australian Surveying and Land Information Group: Canberra).

Austin, M.P., Cawsey, E.M., Baker, B.L., Yialeloglou, D.J., Grice, D.J. & Briggs, S.V. (2000) *Predicted vegetation cover in the Central Lachlan region*. Final Report of the Natural Heritage Trust Project AA 1368.97. CSIRO Wildlife and Ecology, Canberra.

Bayer, R.J. (2001) *Xerochrysum* Tzvelev, a pre-existing generic name for *Bracteantha* Anderb. & Haegi (Asteraceae: Gnaphalieae). *Kew Bulletin* 56: 1015.

Beadle, N.C.W. (1948) *The vegetation and pastures of western New South Wales with special reference to soil erosion* (Government Printers: Sydney).

Beadle, N.C.W. (1981). *The vegetation of Australia* (Cambridge University Press: New York).

Beeston, G.R., Walker, P.J., Purdie, R. & Pickard, J. (1980) Plant communities of the poplar box (*Eucalyptus populnea*) lands of eastern Australia. *Australian Rangelands Journal* 2: 1–16.

Benson, J. (1991) The effect of 200 years of European settlement on the vegetation and flora of New South Wales. *Cunninghamia* 2: 343–370.

Biddiscombe, E.F. (1953) A survey of the natural pastures of the Trangie District, New South Wales, with particular reference to the grazing factor. *Australian Journal of Agricultural Research* 4: 1–28.

Bower, C.C. & Semple, W.S. (1993) *A guide to the eucalypts of the Central West of New South Wales*. Conservation and Land Management Technical Report No. 30.

Costin, A.B. (1954) *A study of the ecosystems of the Monaro region of New south Wales with special reference to soil erosion* (Government Printer: Sydney).

Elix, J. & Lambert, J. (1998) *More than just the odd tree. Report on incentives and barriers to rural woodland conservation, using grassy White Box woodlands as a model*. National Research and Development Program on Rehabilitation, Management and Conservation of Remnant Vegetation, Research Report 1/98.

Faith, D.P., Minchin, P.R. & Belbin, L. (1987) Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69: 57–68.

Harden G.J. (1990–1993) *Flora of New South Wales*. Vols I–IV (New South Wales University Press: Kensington).

Keith, D. (2002) *A compilation map of native vegetation for New South Wales*. Version 1.1 (NSW National Parks and Wildlife Service: Sydney).

Lunt, I.D. & Morgan, J.W. (2001) The role of fire regimes in temperate lowland grasslands of south-eastern Australia. Pp. 177–196. In: Bradstock, R., Williams, J.& Gill, A.M. (Eds) *Flammable Australia: the fire regimes and biodiversity of a continent* (Cambridge University Press: Cambridge, UK).

McCune B., Mefford M.J. (1999) *PC-ORD. Multivariate analysis of ecological data*. Version 4 (MjM Software Design: Oregon, USA).

McDonald, T. (2000) Extending that little bit further. An interview with Martin Driver and Ian Davidson. *Ecological Management and Restoration* 1: 3–9.

Minchin P.R. (1989) *DECODA user's manual* (Australian National University: Canberra).

Moore, C.W.E. (1953a) The vegetation of the south eastern Riverina, New South Wales I. The climax communities. *Australian Journal of Botany* 1: 485–547.

Moore, C.W.E. (1953b) The vegetation of the south eastern Riverina, New South Wales II. The disclimax communities. *Australian Journal of Botany* 1: 548–567.

Moore, R.M. (1959) Ecological observations on plant communities grazed by sheep in Australia. Pp. 500–513. In: Keast, A., Crocker, R.L. & Christian, C.S. (Eds) *Biogeography and ecology in Australia* (Dr. W. Junk: The Hague)

Moore, R.M. (1970) South-eastern temperate woodlands and grasslands. Pp. 169–190. In: Moore R.M. (Ed.) *Australian grasslands* (Australian National University Press: Canberra).

Moore, R.M., Condon, R.W. & Leigh, J.H. (1970) Semi-arid woodlands. Pp. 228–245. In: Moore R.M. (Ed.) *Australian grasslands* (Australian National University Press: Canberra).

Moore, R.M. (1993) Grasslands of Australia. Pp. 315–360. In: Coupland R.T. (Ed.) *Ecosystems of the world 8B. Natural grasslands: Eastern hemisphere and resume* (Elsevier: Amsterdam).

Prober, S.M. (1996) Conservation of the grassy white box woodlands: rangewide floristic variation and implications for reserve design. *Australian Journal of Botany* 44: 57–77.

Prober, S.M. & Austin, M.P. (1991) Habitat peculiarity as a cause of rarity in *Eucalyptus paliformis*. *Australian Journal of Ecology* 16: 189–205.

Prober, S.M. & Thiele, K.R. (1995) Conservation of the grassy white box woodlands: Relative contributions of size and disturbance to floristic composition and diversity of remnants. *Australian Journal of Botany* 43: 349–366.

Prober, S.M., Thiele, K.R. & Higginson, E. (2001) The Grassy Box Woodlands Conservation Management Network: Picking up the pieces in fragmented woodlands. *Ecological Management and Restoration* 2: 179–188.

Seddon, J., Briggs, S. & Doyle, S. (2001) *Birds in woodland remnants of the Central West wheat/sheep belt of New South Wales*. Report to the Natural Heritage Trust, New South Wales National Parks and Wildlife Service, Sydney.

Sivertsen, D.P. & Metcalfe, L.M. (1995) Natural vegetation of the southern wheat-belt (Forbes and Cargelligo 1:250 000 map sheet). *Cunninghamia* 4: 103–208.

Specht, R.L. (1981) Conservation of Vegetation Types. Pp. 393–410. In: Groves, R.H. (Ed.) *Australian vegetation* (Cambridge University Press: Sydney).

Stuwe, J. & Parsons, R.F. (1977) *Themeda australis* grasslands on the Basalt Plains, Victoria: floristics and management effects. *Australian Journal of Ecology* 2: 467–476.

Thomas, V., Gellie, N. & Harrison, T. (2000) *Forest ecosystem classification and mapping for the southern CRA region*. NSW National Parks and Wildlife Service, Southern Directorate. A report undertaken for the NSW CRA/RFA Steering Committee.

Wheeler, D.J.B., Jacobs, S.W.L. & Whalley, R.D.B. (2002) *Grasses of New South Wales* (University of New England: Armidale, NSW).

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Drought-related dieback in four subalpine shrub species, Bogong High Plains, Victoria

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Abstract: Subalpine shrubs on rocky slopes on the Bogong High Plains, Victoria (36° 53' S, 147° 19' E), were observed to be severely desiccated over the summer of 2002/03 after a 50 day period when only 1.2 mm of rainfall was recorded. Moderate to severe canopy dieback was noted in shrubs growing on rocky north- and west-facing slopes. Four shrubs were assessed for their drought tolerance on west-facing slopes at Basalt Hill. Soils were rocky and uniformly shallow across the site (mean depth = 11.32 ± 0.69 cm). *Prostanthera cuneata* was the most drought tolerant species (as evidenced by the least amount of canopy dieback observed) followed by *Hovea montana*, *Pimelea axiflora* var. *alpina* and *Epacris glacialis*. All *Epacris glacialis* plants ($n = 16$) had died at the study location whereas no *Prostanthera cuneata* plants ($n = 45$) had canopy dieback that exceeded 60%. The amount of dieback observed was not significantly associated with either local soil depth or shrub canopy area. Hence, very small plants were not more susceptible to drought nor were shrubs found on the shallowest of the soils at the site. This suggests that drought effects are possibly dependent on local influences such as topography, drainage and competition intensity. Drought has only rarely been considered a major factor affecting the abundance and distribution of subalpine shrub species in Australia but this study suggests that it should be added to the list of abiotic factors governing the local dynamics of subalpine vegetation. In particular, the high mortality of *Epacris glacialis* observed in the study area suggests that non-equilibrium dynamics are likely to be the 'norm' for some shrubs in subalpine areas.

***Cunninghamia* (2004) 8(3): 326–330**

Introduction

The effects of infrequent climatic events such as drought, on the composition of plant communities in south-eastern Australia may be long-lasting (Bureau of Meteorology 1993), but has only rarely been documented. Clearly there is a need to document these effects on Australian vegetation given the propensity for El Nino Southern Oscillation-driven droughts (Fensham & Holman 1999, Rice et al. 2004). Previous studies have used drought-induced dieback to assess the moisture tolerance of tree species at individual sites (Fensham & Holman 1999). Pook et al. (1966) described the effects of drought in forest trees of the Australian Capital Territory and Monaro region during a severe drought in 1965; dry sclerophyll forests were the most severely affected, especially on shallow stony soils on northerly and westerly aspects. Ashton et al. (1975) documented the response of woodland vegetation at Mount Towrong, Victoria during the drought of 1967/8 and found severe damage in vegetation on hot rocky western slopes. Kirkpatrick (1970) assessed the drought resistance of two co-occurring eucalypts in coastal forests at Aireys Inlet, Victoria after the 1967/68 drought, and found one of the species, *Eucalyptus globulus*, was much more impacted than the other, *Eucalyptus tricarpa*. Kirkpatrick and Marks (1985) found that a large number of shrubs and trees suffered drought damage near Hobart, Tasmania during a prolonged drought and observed that damage was most common on shallow soils and gully margins on doleritc soils. All four studies highlight the differing drought resistance of native species, and suggest that explanations for current vegetation patterns need to consider the effects of infrequent extreme events such as drought, more so than has previously been done.

This may be particularly true in alpine and subalpine areas where climatic variability is a noted feature (Costin 1968). While exposure to wind and frost, depth and duration of snow, drainage and disturbance are well known to influence plant community distribution in alpine areas (Williams & Ashton 1987, Costin et al. 2000), the effects of summer drought on local community composition are generally less well-appreciated. Summer drought appears to be relatively common in high mountain areas. Wimbush and Costin (1979) document droughts that occurred in the summers of 1965 and 1978, while Williams (1990) documented drought during the 1982/83 growing season when precipitation was 36% of average, and soil moisture was usually below permanent wilting point.

The effects of drought on subalpine plants are poorly understood. In subalpine grasslands, drought adversely affected the survival and growth of snowgrasses, *Poa* spp., leading to their partial replacement by herbs (Wimbush & Costin 1979, Costin et al. 2000). Williams (1990) reported the effects of drought following severe frost on the growth of four subalpine shrubs, *Grevillea australis*, *Hovea montana*, *Phebalium squamulosum*, *Prostanthera cuneata*. He found that drought sensitivity varied with species, *Hovea* > *Grevillea* > *Phebalium* = *Prostanthera*, and that the impacts of drought differed according to plant size i.e. old 'senescent' plants were more sensitive than young 'building' plants. Pook et al. (1966) also observed that drought effects were evident in subalpine and alpine heaths during the 1965 drought. They found that shrubs on stony ridges e.g. *Podocarpus lawrencei*, *Kunzea muelleri*, were more susceptible to wilting than were shrubs and herbaceous species on deeper, relatively stone-free soils. These studies suggest that infrequent climatic events in alpine areas may play an important role in the distribution of plant species and the structure and composition of plant communities.

Between October 2002 and February 2003, when rainfall was well below-average, shrubs on rocky slopes at Ruined Castle and Basalt Hill on the Bogong High Plains, Victoria were observed to be suffering severe moisture stress. Leaves of severely affected shrubs were browned-off, dry and brittle and contrasted sharply with unaffected leaves. This led the author to undertake field observations to contribute to the sparse literature on drought impacts on subalpine shrubs.

Methods

Study area

The study was conducted within open grassy-heath and closed-heath on west-facing slopes at Basalt Hill on the Bogong High Plains, approximately 4 km east of Falls Creek, Victoria (36° 53' S, 147° 19' E). The site is at 1680 m asl; slopes are short (100 m) and steep (20–30°). Dominant species in the open-heath were *Hovea montana* (Fabaceae) and *Poa costiniana* (Poaceae) while *Prostanthera cuneata* (Lamiaceae) dominated the closed-heaths. Soils were mostly rocky, shallow (range <1–40 cm), acidic, alpine humus soils developed on a parent material of Tertiary basalt. Surface rocks were frequent (>20% cover) across the site. Average rainfall for the area is 1298 mm (Falls Creek recording station, 4 km west of study site; Bureau of Meteorology unpublished data). Mean maximum temperatures are 18.0 °C (March) and mean minimum temperatures are -3.0 °C (July). From October 2002 to February 2003, precipitation was 41% of average (Fig. 1), with no rain recorded for 27 consecutive days (9 January to 6 February). After 1 January, when 18 mm of rainfall was recorded, the following 50 days (to 21 February) had only 1.2 mm of rainfall (Bureau of Meteorology unpublished data). Maximum and minimum temperatures were also well above-average during this period (Fig. 2).

Since the 1850s, summer-grazing of domestic cattle has occurred on the Bogong High Plains but the rocky and steep nature of the study site suggests that grazing pressure is lower there than elsewhere in the region (author pers. obs.). During January 2003, bushfires occurred in subalpine vegetation on the Bogong High Plains and surrounding forests, but did not burn the study area.

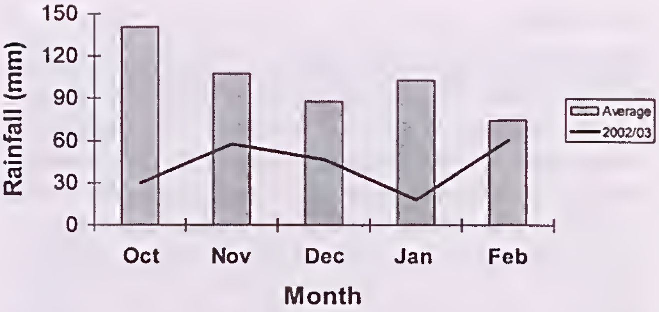

Fig. 1. Monthly rainfall from October 2002 to February 2003 versus the long-term average rainfall for the Falls Creek meteorological recording station.

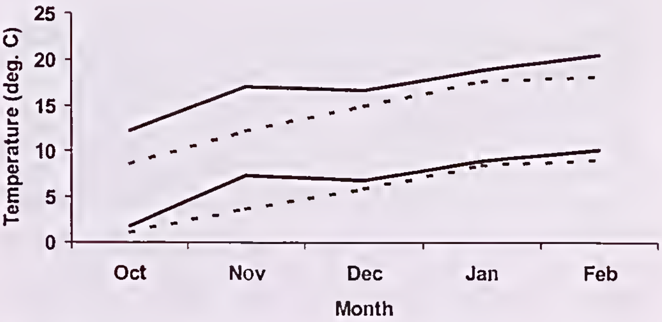

Fig. 2. Mean monthly minimum and maximum temperatures (solid lines) from October 2002 to February 2003 versus the long-term average (dashed line) for the Falls Creek meteorological recording station.

Table 1. Description of the study species, their distribution and the sample sizes used in the study.

Species (Family)	Description and distribution	Sample size (*n*)
Epacris glacialis (Epacridaceae)	Prostrate to decumbent shrub to 30 cm high; common in and around the margins of bogs and in other wet sites such as fens, short alpine herbfield and wet stony areas in sod tussock grassland.	16
Hovea montana (Fabaceae)	Spreading, multistemmed shrub to 0.5 m high; stems ascending or the outer decumbent, sometimes rooting. Usually in open alpine heath and on grassy slopes in subalpine heath at altitudes between 1200 and 1830 m.	88
Pimelea axiflora var. *alpina* (Thymelaeaceae)	Shrub or subshrub, 0.2–1.0 m high. Found in alpine and subalpine habitats above 1500 m, usually in rocky areas.	31
Prostanthera cuneata (Lamiaceae)	Compact dense shrub to 1 m high. Locally common or dominant in alpine closed heathlands between 1500 and 2000 m altitude, mostly in rocky sheltered sites.	45

Study species

The four main shrub species at the site, *Prostanthera cuneata*, *Hovea montana*, *Pimelea axiflora* var. *alpina* and *Epacris glacialis* were selected for study (Table 1). Nomenclature follows Ross (2000). *Prostanthera cuneata* appears to be commonest on deeper soils of lower slopes while *Hovea montana* appears to be common on upper slopes in shallower soils. *Pimelea axiflora* var. *alpina* is found in similar locations to *Hovea montana* while *Epacris glacialis* is confined to shallow soils on lower slopes. All four species produce discrete individuals and population-level responses to drought can be attributed to individuals for each species. Williams (1990) suggested that while *Hovea montana* produces discrete individuals, individuals of *Prostanthera cuneata* are rare or difficult to observe in closed-heath since plants expand by layering of stems. This was not evident at the study site.

Assessment of drought damage

In March 2003, two 75 m long transects were haphazardly located on mid-slope positions on west-facing aspects after reconnaissance of the area. These transects passed through major areas of visible canopy dieback and were used to estimate the relative effects of drought on the four major shrub species present. The line intercept method was used; all shrubs that were intercepted by the transect were recorded and their position noted, their canopy area estimated (using the product of the maximum and minimum widths to obtain a canopy area) and the amount of canopy dieback was estimated by eye using a cover-abundance scale (1 = <10% dieback, 2 = 10–30% dieback, 3 = 31–60% dieback, 4 = 61–99% dieback, 5 = dead). At 1 m intervals, a 5 mm metal pin was pushed into the soil and the depth to bedrock was recorded to the nearest centimetre. Each plant recorded was assigned a soil depth according to the nearest measurement location. This method provides an indication of the local soil depth on which plants were growing rather than an absolute measure.

Data analysis

Data collected from the two transects were pooled for each species to increase sample size. Across species, the association between species and frequency of individuals in each canopy dieback category was analysed using the G-test of independence (Sokal & Rohlf 1981; Quinn & Keough 2003). This tests the goodness of fit of the observed cell frequencies to their expectations (Sokal & Rohlf 1981). Within individual species, the association between the frequency of canopy dieback and (a) canopy size-class (for *Prostanthera*, <10 000 and >10 000 cm^2; for *Hovea* and *Pimelea*, <1000 and >1000 cm^2) and (b) soil depth (<10 cm, >10 cm) was also examined using the G-test of independence.

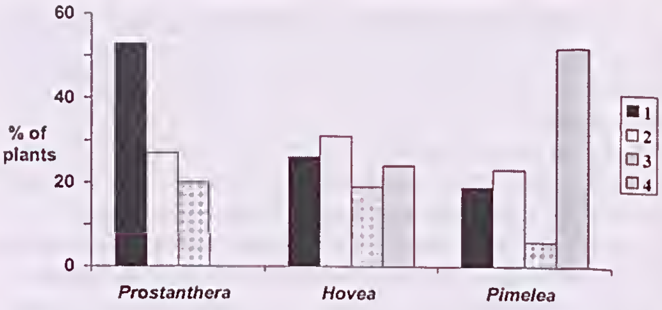

Fig. 3. Frequency of plants observed in canopy dieback categories (1= <10% dieback, 2 = 10–30% dieback, 3 = 31–60% dieback, 4 = >60% dieback) for *Prostanthera cuneata*, *Hovea montana* and *Pimelea axiflora* var. *alpina* at Basalt Hill, Victoria after drought during the 2002/03 growing season.

Results

All *Epacris glacialis* plants (n = 16) recorded were dead at the time of the survey. Leaves were brown and shrivelled but remained on the plant. Drought-induced death occurred regardless of the canopy area of individual shrubs (mean = 1740 cm^2, range = 170–4420 cm^2) and the soil depth on which shrubs occurred (mean = 10.1 cm, range = 4–18 cm).

No mortality was recorded for the other three shrubs. The amount of canopy dieback, however, was not independent of species (G = 40.74, df = 6, $p<0.001$, Fig. 3). All *Prostanthera cuneata* plants had less than 60% canopy dieback whereas 52% of *Pimelea axiflora* var. *alpina* plants exhibited more than 60% canopy dieback. *Hovea montana* had an intermediate response to drought i.e. 24% of plants had >60% canopy dieback. For these three species, the amount of dieback was independent of canopy size (*Prostanthera*: G = 0.76, $p>0.05$; *Hovea*: G = 3.40, $p>0.05$; *Pimelea*: G = 5.66, $p>0.05$) and soil depth on which plants were growing (*Prostanthera*: G = 0.50, $p>0.05$; *Hovea*: G = 2.24, $p>0.05$; *Pimelea*: G = 1.78, $p>0.05$).

Discussion

Over the 2002/03 growing season (October to February) rainfall was 41% of the long-term average, but while this is similar to the rainfall deficit reported by Williams (1990) during 1982/83, it is suspected that the plant responses observed during the present study were most likely the result of the almost complete absence of rain during the warmest months of the year. Over a 50 day period (i.e. most of January and February), only 1.2 mm of rainfall was recorded. Hence, soil moisture stress was likely to have been extreme, particularly given that shallow soils characterise the area. Plant responses are likely to have been determined by the extreme dryness over that period rather than the below-average rainfall for the entire growing season.

The effects of drought on subalpine shrubs were species-specific (as found by Williams 1990), suggesting that the ability to withstand moisture stress is a species trait, and generalisations about drought sensitivity of subalpine shrubs will be unlikely. *Epacris glacialis* was the most drought-sensitive species and *Prostanthera cuneata* the most resilient. *Hovea montana* and *Pimelea axiflora* var. *alpina* showed an intermediate response. Williams (1990) has shown *Prostanthera cuneata* to be drought-resistant elsewhere, while the sensitivity of *Epacris glacialis* is not surprising given that it is mostly found in wet heathland communities (Costin et al. 2000). At Basalt Hill, the distribution of *Epacris glacialis* may reflect its ability to colonise and establish in areas where moisture stress was not severe during most years, perhaps because the basalt-derived soils retain high soil moisture. Only when extreme soil moisture stress was encountered was the species pushed back to more favourable or core habitat (i.e. closer to wetland communities). Similar patch dynamics have been reported for *Eucalyptus obliqua* at Mount Towrong (Ashton & Spalding 2001). Hence, drought has the potential to alter the floristic composition of subalpine communities but the extent of the change will depend on the density and cover of the particular drought-sensitive species present.

It is likely that differences between species in root/shoot ratio, water-use efficiency, ability to withstand severe dehydration and low relative moisture content of leaves may help explain the dieback patterns observed at Basalt Hill (Pook et al. 1966, Ashton et al. 1975). However, no research has been conducted on Australian alpine plants to understand these mechanisms and, although they appear to be important factors elsewhere in Australia (Pook et al. 1966), much work needs to be done to determine their significance in alpine environments.

In subalpine areas, shrubs growing on soils that are the shallowest across the landscape appear to be the most susceptible to drought (Pook et al. 1966, Costin et al. 2000), as they are in other plant communities (Kirkpatrick 1970, Ashton et al. 1975, Kirkpatrick & Marks 1985). This response suggests that drought sensitivity on shallow soils is greatest because plants are growing in areas of the landscape with the least soil moisture storage. Hence, when soils remain below wilting-point for an extended period, shrubs on shallow soils would be expected to show the effects of moisture stress well before shrubs on deeper soils. Given the shallow nature of soils at Basalt Hill (mean = 11.3 cm) and other rocky outcrops such as Ruined Castle, it was perhaps not surprising that drought impacts were observed there, and not elsewhere on the Bogong High Plains, where the soils are generally deeper (Williams & Ashton 1987).

That no significant association between local soil depth and the amount of canopy dieback was found for any species was unexpected, since it was predicted that shallowest soils at Basalt Hill have less capacity to buffer rain-free periods than locally deeper soils. However, it may simply reflect the fact that soils were shallow across the entire site, and deep soil pockets were rare. When previous studies have found that drought effects are moderated by soils, it has usually been because of texture, rather than depth (Pook et al. 1966, Lamb & Florence 1973, see Ashton & Spalding 2001 for an exception). However, texture effects may be moderated by the volume of stones and rocks in the soil profile, as they reduce available water storage. Hence, plants on stony soils may be more susceptible to drought than those plants on stone-free soils, regardless of their texture.

Similarly, no significant association was found for any species between shrub size and the extent of dieback. Canopy area was used as a surrogate for plant age in this study (i.e. small canopy areas were presumed to represent younger plants) as has been done in many studies (e.g. Watt 1947, Williams 1990). Size (and by extension, age) has previously been seen to be an important predictor of drought impacts. Williams (1990) found that senescent shrubs were more susceptible to drought than smaller 'building' shrubs while Pook et al. (1966) found larger diameter trees to be more susceptible to drought effects than smaller trees. By contrast, Kirkpatrick and Marks (1985) found that the smallest individuals of *Eucalyptus pulchella* and *E. viminalis* were the most drought-sensitive, while Fensham and Holman (1999) found that tree dieback during drought in tropical savanna was largely independent of stem size. That no effects of canopy size on drought sensitivity were observed in the present study suggests that the factors that influence local persistence of plants e.g. drainage, microtopography, intra- and inter-specific competitive effects, are also likely to effect the response of individual plants to drought. Local factors are also likely to interact with landscape-scale processes to determine local community composition (Fensham & Holman 1999, Ashton & Spalding 2001).

Conclusion

Summer drought in subalpine areas appears to be relatively frequent at the decadal scale and a potentially important influence on vegetation. Sensitivity to drought will be a species-specific trait, but it appears to be capable of affecting plant community composition and contributing to local patch dynamics. Such patch dynamics in alpine areas have usually been attributed to disturbance events (Williams & Ashton 1988). Indeed, the complete mortality of *Epacris glacialis* in the study area suggests that non-equilibrium population dynamics are likely to be common in some plant communities. Further work, such as that conducted by Ashton et al. (1975) for forest species, is needed to determine the factors that make plants susceptible or resistant to drought in subalpine areas. It will be interesting to observe the length of time it takes plant populations of susceptible species to recover from drought. The preliminary results of the 2002/03 drought event reported here for four shrub species, however, should be treated with caution and be seen within the context of longer-term vegetation dynamics in alpine areas.

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References

Ashton, D.H., Bond, H. & Morris, G.C. (1975) Drought damage on Mount Towrong, Victoria. *Proceedings of the Linnean Society of NSW* 100: 44–69.

Ashton, D.H. & Spalding, D.K. (2001) The ecology of a stressful site: Mount Towrong, Central Victoria 1967–1997. *Australian Forestry* 64: 143–150.

Bureau of Meteorology (1993) Climate of Victoria. In *Flora of Victoria. Volume 1. Introduction.* (eds. D.B. Foreman & N.G. Walsh). pp. 47–60 (Inkata Press: Port Melbourne).

Costin, A.B. (1968) Alpine ecosystems in the Australasian region. In *Arctic and alpine environments* (eds H.E. Wright and W.H. Osburn). pp. 57–87 (Indiana University Press: Bloomington).

Costin, A., Gray, M., Totterdell, C. & Wimbush, D. (2000) *Kosciuszko Alpine Flora* (CSIRO Publishing: Collingwood).

Fensham, R.J. & Holman, J.E. (1999) Temporal and spatial patterns in drought-related tree dieback in Australian savanna. *Journal of Applied Ecology* 36: 1035–1050.

Kirkpatrick, J.B. (1970) Some observations on the relative drought resistance of two eucalypt species near Airey's Inlet. *Victorian Naturalist* 87: 184–186.

Kirkpatrick, J.B. & Marks, F. (1985) Observations on drought damage to some native plant species in eucalypt forests and woodlands near Hobart, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 119: 15–21.

Lamb, D. & Florence, R.G. (1973) Soil moisture and the distribution of two eucalypts. *Australian Forestry* 36: 138–145.

Pook, E.W., Costin, A.B. & Moore, C.W.E. (1966) Water stress in native vegetation during the drought of 1965. *Australian Journal of Botany* 14: 257–267.

Quinn, G.P. & Keough, M.J. (2003) *Experimental design and data analysis for biologists* (Cambridge University Press: Port Melbourne).

Rice, K.J., Matzner, S.L., Byer, W. & Brown, J.R. (2004) Patterns of tree dieback in Queensland, Australia: the importance of drought stress and the role of resistance to cavitation. *Oecologia* 139: 190–198.

Ross (2000) *A census of the vascular plants of Victoria* (Royal Botanic Gardens: Melbourne).

Sokal, R.R. & Rohlf, F.J. (1981). *Biometry.* (W.H. Freeman and Company: San Francisco).

Watt, A.S. (1947) Pattern and process in the plant community. *Journal of Ecology* 36: 1–22.

Williams, R.J. (1990) Growth of subalpine shrubs and snowgrass following a rare occurrence of frost and drought in southeastern Australia. *Arctic and Alpine Research* 22: 412–422.

Williams, R.J. & Ashton, D.H. (1987) The composition, structure and distribution of heathland and grassland communities in the subalpine tracts of the Bogong High Plains, Victoria. *Australian Journal of Ecology* 12: 57–71.

Williams, R.J. & Ashton, D.H. (1988) Cyclical patterns of regeneration in subalpine heathland communities on the Bogong High Plains, Victoria. *Australian Journal of Botany* 36: 605–619.

Wimbush, D.J. & Costin, A.B. (1979) Trends in vegetation at Kosciusko. III. Alpine range transects, 1959–1978. *Australian Journal of Botany* 27: 833–871.

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Vegetation of Werakata National Park, Hunter Valley, New South Wales

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Abstract: Werakata National Park (32° 50 S, 151° 25 E), near Cessnock in the Hunter Valley of New South Wales, conserves 2145 ha of mostly open forest vegetation, which was formerly widespread in the lower Hunter Valley. Six vegetation communities are delineated; Lower Hunter Spotted Gum – Ironbark Forest occupies most of the Park. All communities present are considered to be poorly conserved in the region and Werakata plays a critical role in the protection of these vegetation types. Two vegetation communities, Kurri Sand Swamp Woodland and Hunter Lowlands Redgum Forest, are listed as Endangered Ecological Communities under the NSW *Threatened Species Conservation Act 1995*, while others may warrant future listing. Considerable variation in the floristic composition of the Kurri Sand Swamp Woodland is apparent in the area and the implications are discussed. Populations of four vulnerable plant taxa — *Callistemon linearifolius, Eucalyptus parramattensis* subsp. *decadens, Eucalyptus glaucina, Grevillea parviflora* subsp. *parviflora,* and two rare plant taxa — *Grevillea montana, Macrozamia flexuosa*, together with several other regionally significant species occur within Werakata.

Recommendations are made on the conservation of plant taxa and vegetation communities in the Cessnock area, and on general reserve management. It is suggested that further areas be added to the reserve to consolidate and expand upon that which is already contained, particularly in regard to threatened species, and endangered and poorly conserved ecological communities.

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Introduction

Werakata National Park (32° 50 S, 151° 25 E) occupies 2145 ha of dry sclerophyll forest near Cessnock in the lower Hunter Valley of eastern New South Wales. It was gazetted as a conservation reserve in January 2002, as a result of joint Commonwealth and NSW forest reform process, having been previously managed by State Forests of NSW for timber production. Flora survey and mapping of the vegetation of Werakata National Park was undertaken on behalf of the Central Coast – Hunter Range region of the NSW National Parks and Wildlife Service, to examine the vegetation of the area from a management perspective, particularly in relation to fire (Bell 2001a). This paper presents the results of that survey.

Location and environmental setting

The Cessnock district comprises a mixture of urban, agricultural, mining, viticultural and bushland areas, including tracts of public bushland (e.g. Cessnock, Aberdare, Heaton, Pokolbin and Corrabare State Forests; Yengo, Watagans and Werakata National Parks; and Crown reserves). Werakata National Park occupies four distinct parcels of land centred around Cessnock. Previously managed by State Forests of NSW, they remain contiguous with this tenure (Table 1, Fig. 1). Regionally, Werakata NP lies within the largest patch of remnant vegetation on the Hunter Valley floor.

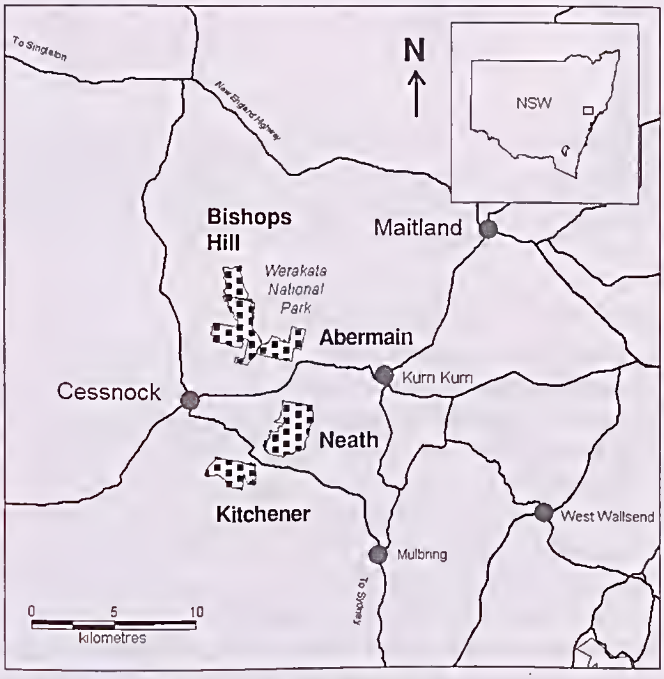

Fig. 1. Location of Werakata National Park

Table 1. Portion name, size and previous land uses, Werakata NP.

Portion size (ha)	Location	Previous tenure part of
Kitchener (361 ha)	between Kitchener & Kearsley, ~5km SE of Cessnock	Aberdare SF
Neath (652 ha)	between Neath & Mt Tomalpin, ~6km E of Cessnock	Aberdare SF
Abermain (316 ha)	between Abermain & Old Maitland Rd, Maitland Rd, ~6km ENE of Cessnock	Aberdare SF
Bishops Hill (816 ha)	between Old Maitland Rd & Lochinvar Rd, ~5km NNE of Cessnock	Cessnock SF

The lower Hunter Valley lies within the Sydney Basin bioregion which stretches from the upper Hunter Valley (Liverpool Range), to Port Stephens on the coast, and south to Batemans Bay. The bioregion covers approximately 36 655 km^2, and is composed of Mesozoic sandstones and shales; dissected plateaus; forests, woodlands and heaths; skeletal soils, sands and podzolics (Thackway & Cresswell 1995).

Werakata NP falls within a warm temperate climatic zone, with warm wet summers and cool dry winters. Rainfall generally peaks in late summer and early autumn, although local variations due to topography are evident. There is an annual average of 748 mm per year. Temperatures range from a daily average low of 4° C in July, to a high of 30° C in December, January and February (Table 2).

Table 2. Annual average climatic data for Cessnock, 80 m ASL (<10 km from all NP portions).

(Source: Bureau of Meteorology 2001).

Month	Mean rainfall (mm)	Temperature (°C) Minimum	Temperature (°C) Maximum
January	79	17	30
February	88	17	30
March	78	16	29
April	66	12	25
May	59	8	21
June	60	6	18
July	45	4	18
August	40	5	19
September	42	8	22
October	55	11	25
November	59	14	28
December	76	16	30
Annual	748	–	–

Land use

Following the Comprehensive Regional Assessments (CRAs) of the late 1990s, Regional Forest Agreements (RFAs) were signed by State and Commonwealth governments for major forest areas of New South Wales. During this process, several broad forest ecosystems in the lower Hunter Valley were recognised as being poorly conserved and heavily depleted by past clearing (NPWS 1999). Portions of Cessnock and Aberdare State Forests were consequently transferred to national park estate to create Werakata National Park. Prior to gazettal as national park, Aberdare and Cessnock State Forests were managed for timber production, principally for their ironbarks, mostly *Eucalyptus fibrosa*, and Spotted Gum *Corymbia maculata*. Such timbers were used for mining props in the surrounding coal mines. Aberdare State Forest was originally proclaimed in 1963, with additions made during the 1970s (EJE Group 1995). Prior to this, timber from the forest was used in local underground coal mines and the building industry. The construction of privately owned railway lines for transportation of coal in the early 1900s facilitated this practice. Cessnock State Forest was proclaimed in 1942, and was extended several times during the 1940s and 1950s. Historical artefacts (e.g. railway cuttings & easements, switch houses) of significance apparently still remain in both areas (EJE Group 1995).

Based on known occupation elsewhere in the Hunter Valley, it is likely that this area also provided important homelands for Aboriginal people, though an archeological investigation (Kinhill Engineers 1995) found negligible evidence for occupation by Aboriginal people in Cessnock or Aberdare State Forests. The long history of European disturbance may have disturbed remaining artefacts.

Landforms, geology and soils

Werakata NP comprises gently undulating-to-steep hills with an elevational range of 40 to 110m ASL. Drainage is directed into two Hunter River sub-catchments, Black Creek catchment west of Neath, and Wallis/ Swamp Creek catchment to the east. The highest point in the local area is Mount Tomalpin (201m ASL), but this is not in the Park.

Geologically, Werakata NP lies predominantly within the Branxton Formation (Maitland Group) and Rutherford Formation (Dalwood Group) of the Permian sediments of the Hunter Valley, within the northern section of the Sydney geological basin (Rasmus et al. 1969). Soil landscapes (Kovac 1991; Kovac and Lawrie 1991) mapped within Werakata are; Aberdare (approx. 31% of the study area), Neath (34%), Rothbury (14%) and Branxton (21%) (Table 3). Kovac and Lawrie (1991) describe the soil landscapes as follows:

Aberdare: rolling low hills of Yellow (orange) Podzolic Soils on upper and mid slopes, Red Podzolics and Brown Podzolics on the steeper slopes, and Alluvial Soils (sands) in some drainage lines; **Neath**: gently undulating rises of grey Solodic soils in poorly drained areas associated with exposed coal seams, and Yellow Solodic Soils on the better drained lower slopes; **Rothbury**: undulating and rolling low hills of Red Podzolic Soils on upper slopes, Yellow Podzolics on midslopes, Yellow Solodic Soils and Brown Soloths on lower slopes, and Praire Soils in drainage lines; **Branxton**: undulating low hills and rises with many small creek flats, main soils being Yellow Podzolic Soils on midslopes, Red Podzolic Soils on crests, Yellow Soloths on lower slopes and drainage lines, and Alluvial Soils (sands) occur in some creeks with Siliceous Sands on flats within large valleys.

Table 3. Geology and soil landscapes occurring in Werakata National Park (from Kovac 1991).

Werakata Portion	Geology	Soil landscapes
Kitchener	Branxton Formation (Maitland Group)	Neath; Aberdare
Neath	Branxton Formation (Maitland Group)	Neath; Aberdare
Abermain	Rutherford & Farley Formations (Dalwood Group); Greta Coal Measures	Neath; Aberdare; Rothbury
Bishops Hill	Rutherford & Farley Formations (Dalwood Group)	Branxton; Aberdare: Rothbury

Table 4. Significant flora within a 20 km radius of the centre of Werakata National Park.

TSC = NSW Threatened Species Conservation Act 1995; End = Schedule 1 (Endangered); Vul = Schedule 2 (Vulnerable). See Briggs and Leigh (1996) for explanation of rare status codes.

Species	Status	Location	Source
Eucalyptus castrensis	TSC End	Singleton army base	Hill & Stanberg (2002)
Persoonia pauciflora	TSC End	North Rothbury	Patrick (1999)
Callistemon linearifolius	TSC Vul	Aberdare SF Werakata NP	Binns (1996) Binns (1996)
Eucalyptus fracta	TSC Vul	Pokolbin SF	NPWS Atlas
Eucalyptus parramattensis subsp. *decadens*	TSC Vul	Mulbring Road, Mulbring Tomalpin area Lomas Lane, Nulkaba	pers. obs. NPWS Atlas pers. obs.
Eucalyptus pumila	TSC Vul	Pokolbin SF	NPWS Atlas
Tetratheca juncea	TSC Vul	Heaton SF Sugarloaf Range	Binns (1996) NPWS Atlas
Acacia sp A	Rare (2RC)	Aberdare SF	Bell & Murray (2001)
Callistemon shiressii	Rare (3RC-)	Bow Wow Creek catchment	Bell & Murray (2001)
Macrozamia flexuosa	Rare (2K)	Bow Wow Creek catchment Neath North Rothbury	Bell & Murray (2001) Bell (1996) Patrick (1999)
Eucalyptus fergusonii subsp. *dorsiventralis*	Rare (2RC-)	Murrells Rd, Heaton SF Summit Point, Heaton SF Bow Wow Creek catchment	Bell (2000) Bell (2000) Bell & Murray (2001)
Eucalyptus fergusonii subsp. *fergusonii*	Rare (2RC-)	North Rothbury	Patrick (1999)
Grevillea montana	Rare (2KC-)	Neath Singleton army base	Bell (1996) pers. obs.

Previous botanical studies

Before the current work, there was no comprehensive vegetation survey of Werakata National Park. Binns (1996) completed four plot-based survey sites within the then Aberdare and Cessnock State Forests, as part of the Morisset Forestry District environmental impact assessment. This work involved survey of an area of approximately 112 000 ha incorporating fifteen State Forests. A total of 146 survey plots were undertaken across this area, representing a coverage of approximately 1 plot per 770 ha. Based on the four plots from what is now Werakata, Binns (1996) determined that Grassy Sclerophyll Forest (MORf1: *Eucalyptus punctata*, *Corymbia maculata*, *Allocasuarina torulosa*; & MORf4: *Eucalyptus fibrosa*, *Corymbia maculata*) dominated the reserve.

The Lower Hunter and Central Coast Regional Environmental Management Strategy (LHCCREMS) undertook a survey, classification and mapping project for the Cessnock, Maitland, Newcastle, Lake Macquarie, Port Stephens, Wyong and Gosford LGAs (NPWS (2000). This study attempted to define and map all vegetation within a 563 000 ha area, and included Werakata. Vegetation communities determined by NPWS (2000) to be present comprised Central Hunter Riparian Forest (Unit 13), Lower Hunter Spotted Gum–Ironbark Forest (Unit 17), Hunter Lowlands Redgum Forest (Unit 19), and Kurri Sand Swamp Woodland (Unit 35).

Bell and Murray (2001) examined the ecological significance of the Bow Wow Creek catchment in the Quorrobolong Valley, approximately 4km south-east of Werakata. This study provides useful distributional information on significant species, and identified a rainfall gradient along the Broken Back Range which is reflected in the regional vegetation.

Significant plant species in the Cessnock LGA were documented in Fallding and Bell (1996), and more recently in Murray et al. (2001). These are based on the NPWS Wildlife Atlas database, augmented with unpublished and personal records, and provide background information on those species potentially occurring in Werakata. Of particular interest is the recently discovered and highly endangered *Persoonia pauciflora*, which occurs within approximately 5 km of the park in similar habitat to that found in Werakata (Weston 1999). Table 4 summarises significant plant species previously known from within approximately 20 km of Werakata. Other regionally significant flora within this area include disjunct distributions of *Eucalyptus longifolia* and *Eucalyptus racemosa* along Sandy Creek Road (Bell & Murray 2001) and *Eucalyptus squamosa* in part of Aberdare State Forest (pers. obs.).

Methods

Survey of Werakata NP was structured so that new data could be incorporated with the large amount of existing regional data already available (e.g. NPWS 2000). Methods followed standard techniques so that re-analysis of all regional data, including that from Werakata, could be undertaken in the future. During the present study, funding was made available for 15–20 new sites to be surveyed.

Aerial photographic interpretation

Stereoscopic colour aerial photographs (Cessnock 1:25 000 scale 1994) were used to map broad vegetation patterns within Werakata. Photopatterns and visible trails were transferred onto a map overlay for survey site location and ground truthing. Broad structural vegetation types identified included Open Forest, Scrub, Swamp Forest and Cleared areas.

Site stratification

The selection of new field survey sites involved consideration of major environmental variables (as per Wilson et al. 1997). As there was little variation in topography and aspect throughout the reserve, sites were originally determined within a *soil landscape-broad vegetation* stratification, such that all possible combinations of these variables were sampled (Table 5). Due to the small size of the reserve relative to the number of *soil landscape-broad vegetation* strata (three broad vegetation classes by four soil landscapes = 12 strata), and the limited funding available, the location of sites was only broadly based on this structure. The final location of survey sites relied heavily on broad vegetation patterns observed through aerial photographic interpretation, but with reference to soil landscape distribution.

The number of replicates within each stratification class directly reflected the extent to which that class was represented within the reserve. Areas subjected to recent fire (generally <3 years) were avoided as far as possible. At the time of survey (January 2001), fire occurred in part of the reserve near Abermain, and hence only canopy dominants were evident in this area.

Table 5. Stratification of sampling sites and % within Werakata. Total area of vegetation, 2052 ha (excluding 93 ha cleared).

	Landscape broad vegetation			
	Open-forest ha (87%)	**Swamp Forest ha (5%)**	**Scrub ha (8%)**	**Total area ha (100%)**
Neath	664 (32%)	70 (3%)	83 (4%)	817 (39%)
Aberdare	519 (25%)	2 (0%)	2 (0%)	523 (25%)
Branxton	358 (1%)	20 (1%)	66 (3%)	444 (22%)
Rothbury	235 (12%)	9 (0%)	24 (1%)	268 (13%)

Floristic survey

Survey methods followed Wilson et al. (1997). Within each 0.04 ha survey site, all vascular plant species present were recorded and given a cover abundance rating, based on a modified Braun-Blanquet scale (see Walker & Hopkins 1990). Physical attributes (such as vegetation structure, soil type, elevation, slope, aspect, physiographical position) were recorded, and photographs taken for later reference. Previous familiarity with the vegetation assisted the identification of most species that were not flowering or fruiting during this time. Despite this, a small number of species could not be confidently assigned to subspecies or varietal rank with certainty. Voucher specimens of unknown or significant status were collected for later identification or lodgement with the National Herbarium of New South Wales. Plant taxonomy followed that of Harden (1990–93; 2002) and Harden and Murray (2000), together with subsequent taxon-specific revisions which have been generally accepted by the National Herbarium of New South Wales.

Field survey was carried out over three months between December 2000 and February 2001. Seventeen full floristic plots were completed during the survey, and combined with the existing plot data totalled 21 sites. While moving between plots on foot and in 4WD vehicle, the distributions of vegetation community types were noted, and searches for significant plant species were made. Cropper (1993) and Keith (2000) indicate that the detection of rare or threatened plant species is often best achieved through general reconnaissance traverses. Levels of disturbance, weed invasion and fire history of the area could also be assessed.

Data analysis and vegetation classification

Cluster analysis (UPGMA using both the Bray-Curtis and Kulzcynski coefficients of dissimilarity, and default settings) were performed on site data using the PATN Statistical Analysis Package (Belbin 1995a, 1995b), following similar works elsewhere (eg: Keith & Bedward 1999; Griffith et al. 2000). Belbin (1991) provides detailed discussion on how ecological data are analysed using this program. A review of taxonomy was undertaken prior to analysis to ensure consistent nomenclature was applied to the entire dataset, including existing State Forest data.

Vegetation mapping

Floristic communities for the whole of Werakata were mapped using a combination of broad vegetation types, cluster analysis of survey data, knowledge of the ground situation and re-examination of aerial photographs. The small size of the reserve and the high number of tracks and trails present facilitated detailed ground truthing of community boundaries. During this process, refinements to the regional mapping of NPWS (2000) were also undertaken.

Results

Floristic survey

A total of over 190 plant taxa were recorded during the survey (Appendix 1). Cluster analysis of vegetation data (21 sites) using the Bray-Curtis coefficient and the default PATN settings revealed the presence of six groups of sites at the 0.9 level of dissimilarity, upon which five vegetation communities are based (Figure 2). One additional community of very restricted distribution was not sampled, and hence does not occur in the dendrogram. Apparent discrepancies in parts of the dendrogram can be explained by disturbance history of the component sites, where *Melaleuca nodosa* becomes an important and dominant component in the understorey.

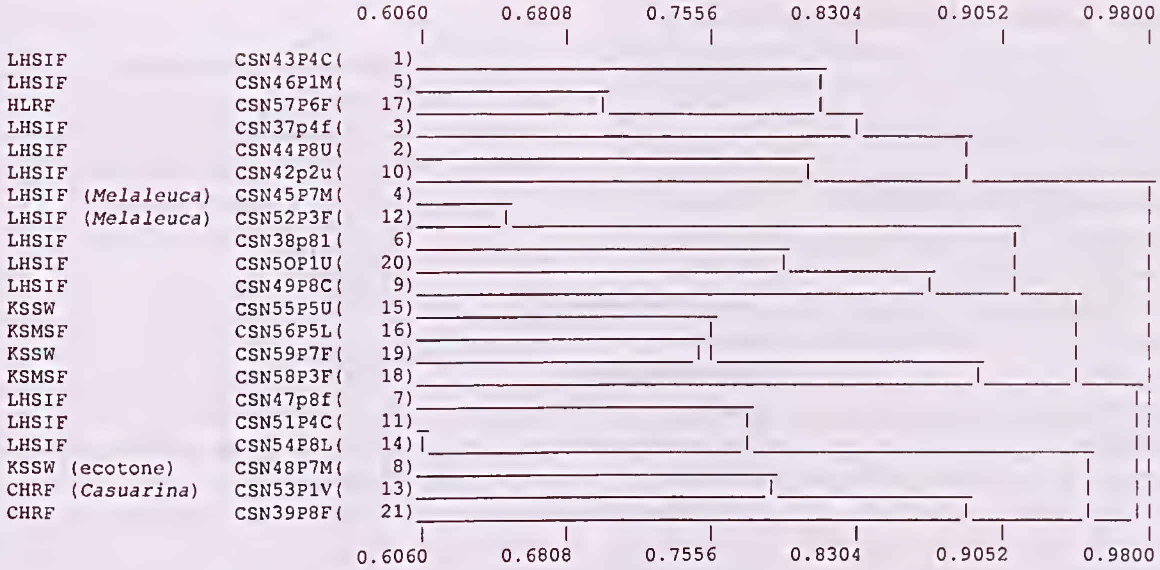

Fig. 2. Dendrogram of survey sites. LHSIF = Lower Hunter Spotted Gum-Ironbark Forest (Unit 1); CHRF = Central Hunter Riparian Forest (Unit 2); HLRF = Hunter Lowlands Redgum Forest (Unit 3); KSSW = Kurri Sand Swamp Woodland (Unit 4); KSMSF = Kurri Sand Melaleuca Scrub-Forest (Unit 5).

As far as possible the nomenclature of NPWS (2000) has been applied to the six vegetation communities delineated. Appendix 2 summarises the main features of the six vegetation communities identified. Patterns in vegetation distribution throughout Werakata are illustrated (Fig. 3), based on the original 1:25 000 scale mapping.

Significant taxa

Although small in area, Werakata National Park fills an important role in the conservation of vegetation communities and flora species that are poorly reserved throughout the lower Hunter Valley. The current study identified over 190 plant taxa and six vegetation communities. Werakata is part of a regional corridor linking sizeable areas of bushland around Cessnock (including State Forests), south to the Watagan Range (Bell & Murray 2001).

Species of conservation significance recorded within Werakata include four listed as vulnerable under the TSC Act (*Callistemon linearifolius*, *Grevillea parviflora* subsp. *parviflora*, *Eucalyptus glaucina*, *Eucalyptus parramattensis* subsp. *decadens*), two rare (*Grevillea montana*, *Macrozamia flexuosa*) and several species of regional significance (Table 6). Regional significance is based on the listing of species maintained by the Rare Plants Subcommittee of the Hunter Region Botanic Gardens. Specimens of all significant species have been lodged at the National Herbarium of New South Wales.

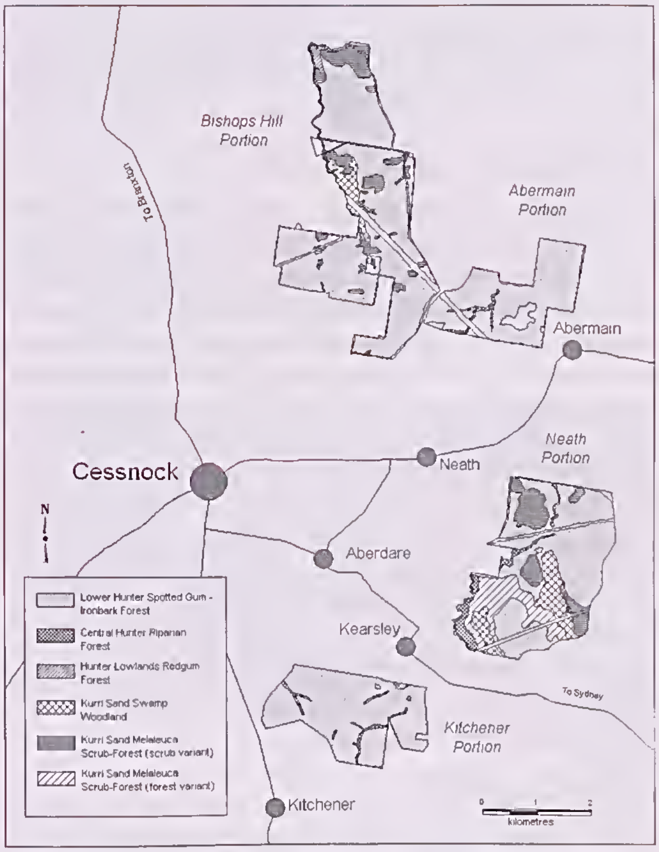
Bishops Hill Portion
To Branxton
Abermain Portion
Abermain
Cessnock
Neath
Neath Portion
N
Aberdare
Kearsley
To Sydney
Kitchener Portion
Kitchener
Lower Hunter Spotted Gum - Ironbark Forest
Central Hunter Riparian Forest
Hunter Lowlands Redgum Forest
Kurri Sand Swamp Woodland
Kurri Sand Melaleuca Scrub-Forest (scrub variant)
Kurri Sand Melaleuca Scrub-Forest (forest variant)
0 1 2
kilometres

Fig. 3. Patterns in vegetation distribution in Werakata NP.

Callistemon linearifolius

Occurs in dry sclerophyll forest on the coast and adjacent ranges chiefly from the Georges River south of Sydney to the Hawkesbury River (Spencer & Lumley 2002). Binns (1996) recorded *Callistemon linearifolius* from four locations in Aberdare and Cessnock State Forests, two of which lie within Werakata. This species was also recorded in the Neath portion during the current survey, within the understorey of Lower Hunter Spotted Gum–Ironbark Forest [Unit 1]. Both existing and new records of *Callistemon linearifolius*

Table 6. Significant plant taxa, Werakata National Park.

Species	Significance	Occurrence in Werakata NP
Callistemon linearifolius	TSC Vul	Neath & Kitchener portions
Grevillea parviflora subsp. *parviflora*	TSC Vul	Kitchener portion
Eucalyptus glaucina	TSC Vul	north-western Bishops Hill portion
Eucalyptus parramattensis subsp. *decadens*	TSC Vul	Bishops Hill & Neath portions
Grevillea montana	Rare 2KC-	all portions
Macrozamia flexuosa	Rare 2K	all portions
Acacia deanei subsp. *deanei*	range extension onto NC	Neath portion
Acacia linifolia	uncommon on Permian Sediments	Bishops Hill portion
Angophora bakeri	restricted distribution	Kitchener and Bishops Hill portions
Babingtonia pluriflora	near Sth limit of distribution	Swamp Creek, Neath portion
Corymbia eximia	Nth limit of distribution	Kitchener portion, mostly on exposed crests
Dianella prunina	uncommon	Kitchener portion
Eucalyptus canaliculata	near Sth limit of distribution	Deadmans Creek, Bishops Hill portion
Eucalyptus agglomerata	atypical form	most areas
Lomandra cylindrica	northern limit of distribution	throughout the park

confirm that this species occurs within the North Coast botanical subdivision, and probably represent the known northern limit of the species. This species is currently listed as vulnerable (Schedule 2) on the NSW *Threatened Species Conservation Act 1995*, and carries a conservation risk code of 2RCi (Briggs & Leigh 1996).

Grevillea parviflora subsp. *parviflora*

A low-spreading, dense to erect open shrub 0.3–1 m tall, occurring from north-western Sydney to Cordeaux-Appin area, in moist heath or woodland on clay soils (Olde & Marriot 1995; McGillivray 2000). Within Werakata, this subspecies is locally common in the southern portion near Kitchener, where it occurs in the understorey of Lower Hunter Spotted Gum–Ironbark Forest [Unit 1] with *Grevillea montana*. No other locations were found in the reserve, although it is possible that this taxon occurs in small, localised populations throughout the area. Both *Grevillea parviflora* subsp. *parviflora* and *Grevillea parviflora* subsp. *supplicans* have been listed on the NSW *Threatened Species Conservation Act 1995*, the former as vulnerable (Schedule 2). *Grevillea parviflora* subsp. *parviflora* was previously not known from any conservation reserve in the Hunter Valley area, nor from elsewhere within its known distribution (NSW Scientific Committee 1998).

Eucalyptus glaucina

A tree to 30 m in height, locally frequent but sporadic in grassy woodland on deep, moderately fertile and well-watered soils near Casino and from Taree to Broke (Hill 2002). A small population of *Eucalyptus glaucina* is present in the north-western corner of the Bishops Hill portion of Werakata, where it occurs in Hunter Lowlands Redgum Forest [Unit 3] with *Eucalyptus tereticornis*, *Eucalyptus amplifolia* subsp. *amplifolia* and occasionally *Eucalyptus moluccana*. This site appears to have been grazed in the past, leaving an open grassy understorey with only scattered shrubs in parts. On the northern side of Deadmans Creek (outside the reserve), the understorey appears less disturbed, and it is possible that further specimens of *Eucalyptus glaucina* occur there. Binns (1996) did not record *Eucalyptus glaucina* from anywhere within the Morisset forestry district, but suggested that if it did occur it would most likely be on the lower slopes or valley flats of Pokolbin State Forest (~15 km to the west). This species is currently listed as vulnerable (Schedule 2) on the NSW *Threatened Species Conservation Act 1995*, and is also listed as 3VCa by Briggs and Leigh (1996). Reserved populations of *Eucalyptus glaucina* are known only from Selection Flat Flora Reserve on the NSW North Coast, where more than 1000 individuals are thought to occur (Briggs & Leigh 1996).

Eucalyptus parramattensis subsp. *decadens*

A small, smooth barked tree, locally frequent in dry sclerophyll woodland on sandy soils in low, often wet sites at Tomago and Kurri (Hill 2002). Within Werakata *Eucalyptus parramattensis* subsp. *decadens* has a limited distribution mainly in association with the Neath soil landscape and occurs in the Kurri Sand Swamp Woodland [Unit 4] and nearby areas. Widely scattered individuals also occur in the Kurri Sand Melaleuca Scrub-forest [Unit 5], particularly in the zone of integration between these two communities. The vast majority of the Kurri population of this subspecies occurs outside Werakata. *Eucalyptus parramattensis* subsp. *decadens* is currently listed as vulnerable on Schedule 2 of the NSW *Threatened Species Conservation Act 1995*, and apart from the Werakata NP populations, there are no other occurrences within dedicated conservation reserve (Murray et al. 2001). Extensive populations of this subspecies do occur on the Tomago Sandbeds north of Newcastle, a protected area managed by the Department of Land and Water Conservation for emergency water supplies to the urban areas of Newcastle (Bell & Fallding 2002.).

Grevillea montana

A low shrub restricted to the southern rim of the Hunter Valley from Denman to Kurri Kurri (Makinson 2002; Olde & Marriott 1994). Binns (1996) indicated that this species occurs in both Cessnock and Aberdare State Forests, although there is no indication of population sizes at either location. During the current survey, *Grevillea montana* was found to be abundant in the Kitchener portion of the reserve, scattered in the Neath portion, abundant in the southern section of the Abermain portion, and locally abundant in the Bishops Hill portion. In most cases, the favoured habitat appears to be the sandy clay loams supporting the Lower Hunter Spotted Gum-Ironbark Forest [Unit 1], although it also occurs in the Kurri Sand Swamp Woodland [Unit 4]. This species is currently listed as a rare species by Briggs and Leigh (1996), with a conservation code of 2KC-. In recent years, survey work in national parks and other protected areas (e.g. Wollemi NP, Yengo NP, Myambat Logistics Company, Singleton Military Area) has revealed substantial populations which suggest the revision of this code to 2RCa (Bell 2001b).

Macrozamia flexuosa

A cycad occurring generally from Bulahdelah to Lake Macquarie (Hill 1998). It is distributed widely throughout Werakata, particularly in the southern portions where it often occurs with *Macrozamia reducta*. Sizable populations also exist in the southern section of the Bishops Hill portion. Habitat preference is generally tied to the Lower Hunter Spotted Gum – Ironbark Forest [Unit 1], tending to predominate more on conglomerate-derived soils. *Macrozamia flexuosa* is a rare species currently listed with a conservation code of 2K (Briggs & Leigh 1996). Reserved populations are known from Glenrock SRA (Bell 1998a), Lake Macquarie SRA and Pulbah Island NR (Bell 1998b), and within Council reserves in Lake Macquarie LGA (Bell & Helman in prog.).

Significant vegetation types

All six vegetation communities present within Werakata are considered to be poorly conserved in the region. Two are currently listed as Endangered Ecological Communities under the NSW *Threatened Species Conservation Act 1995*, while one community potentially qualifies for listing due to declines in distribution. The remaining three communities are considered significant at the local and regional level, and may warrant listing when further information becomes available.

Kurri Sand Swamp Woodland [Unit 4]

Kurri Sand Swamp Woodland (NPWS 2000) is listed as an Endangered Ecological Community (EEC) under the TSC Act, and is broadly consistent with some of the vegetation present in Werakata. However, there appear to be characteristic differences in the dominant and component species. As an example of these differences, the final determination for the Kurri Sand Swamp Woodland includes canopy species such as *Eucalyptus parramattensis* subsp. *decadens*, *Angophora bakeri*, and occasionally *Eucalyptus signata* and *Eucalyptus sparsifolia*. In contrast, canopy species dominating in Unit 4 include *Angophora bakeri*, *Eucalyptus resinifera* subsp. *resinifera*, and *Eucalyptus agglomerata*, with *Eucalyptus parramattensis* subsp. *decadens* and *Corymbia gummifera* occasionally present. In addition, *Eucalyptus resinifera* subsp. *resinifera* and *Corymbia gummifera* are not included in the final determination of the Kurri Sand Swamp Woodland. Despite this, the overall description of the community, particularly its biophysical components, is consistent with the determination. Approximately 70 ha of this community have been mapped for Werakata.

The Kurri Sands Swamp Woodland and its variations also show strong affinities to vegetation on parts of the Cumberland Plain in western Sydney. Tozer (2003) describes and maps the natural vegetation of that area, and identifies four communities occurring on two different deposits of Tertiary alluvium. The distribution of these four communities is reportedly related to the extent of exposure of soils from three depositional phases, and local drainage conditions. Consequently, vegetation dominated by ironbarks, Castlereagh Ironbark Forest, occurs on soils with high clay content, while more sandy soils support Scribbly Gum, Castlereagh Scribbly Gum Woodland. Typically, soils with high clay content underlie sandy soil but tend to be exposed through erosion around the edges of deposits. Poorly-drained depressions support a swamp woodland, Castlereagh Swamp Woodland, while shallow deposits of Tertiary alluvium over shale soils, or localised concentrations of iron-indurated gravels, support a transitional forest, Shale Gravel Transition Forest. A fifth community, with a sparse canopy and a dense understorey of *Melaleuca nodosa*, Cooks River Clay Plain Scrub Forest, was included as a sub-unit of the Castlereagh Ironbark Forest.

When compared to the vegetation in the Kurri-Cessnock area, there are strong similarities evident. In particular, information available to date (both from work in Werakata and elsewhere) suggests that the Kurri Sands Swamp Woodland (in the broadest sense) would perhaps include a sand-based component characterised by Scribbly Gums (*Eucalyptus signata* and/or *E. racemosa*) and *Angophora bakeri*; a clay-based forest dominated by ironbarks; a clay-based scrub-forest dominated by *Melaleuca nodosa* (Unit 5: Kurri Sand Melaleuca Scrub-Forest); a drainage depression community where *Eucalyptus parramattensis* subsp. *decadens* is prevalent; and possibly a transitional forest where *Eucalyptus resinifera*, *Eucalyptus agglomerata* (atypical form) and *Angophora bakeri* occur (Unit 4: Kurri Sand Swamp Woodland). Extensive survey and analysis of the Kurri Sands proper is required to better understand these floristic relationships.

Hunter Lowlands Redgum Forest [Unit 3]

Hunter Lowlands Redgum Forest was identified as a regionally significant vegetation community by NPWS (2000), and has since been listed as an Endangered

Ecological Community under the NSW *TSC Act*. A reduction in area of approximately 73 % has been estimated by NPWS (2000) for this community since European occupation.

Within Werakata, this community is restricted to the far north-western corner of the Bishops Hill portion, where it occupies an area of approximately 7 ha. Although NPWS (2000) map the Hunter Lowlands Redgum Forest for several areas throughout Werakata, in reality this community is restricted to the one patch. The occurrence in Werakata is the only stand within a conservation reserve in the Hunter region, and consequently there is an urgent need to secure further reservation of this community elsewhere in the region. In addition, the stand in Werakata has added significance due to the presence of *Eucalyptus glaucina*, a species listed as vulnerable on the NSW *TSC Act 1995*.

Lower Hunter Spotted Gum–Ironbark Forest (Unit 1)

The Lower Hunter Spotted Gum-Ironbark Forest represents a vegetation type that was formerly quite widespread on the floor of the Hunter Valley (NPWS 2000). Forests between Beresfield and Cessnock represent the core of its distribution, although much of this occurs in State Forest and has been managed for timber production for many years. NPWS (2000) have mapped an extant distribution of 27000 ha, which they estimate represents a reduction of 59 % of its former range.

Werakata supports a sizeable component of the conserved portion of this vegetation type for the region. Approximately 1600 ha have been mapped from the current study, while NPWS (2000) report 1873 ha from all reserves. Consequently, Werakata plays a critical role in the regional conservation of this vegetation community.

Kurri Sand Melaleuca Scrub–Forest [Unit 5]

Small localised areas in close proximity to the Kurri Sand Swamp Woodland [Unit 4] support a dense *Melaleuca* scrub with occasional stunted eucalypt emergents, described in this paper as Kurri Sand Melaleuca Scrub-Forest [Unit 5]. This vegetation type occurs on clay pans probably associated with the sandy deposits that generally typify the Kurri Sands Swamp Woodland. It was not identified or mapped as distinct by NPWS (2000) in their regional vegetation study. This community differs substantially in floristic composition from the *TSC Act*-defined Kurri Sands Swamp Woodland [Unit 4], and characteristically comprises a very dense layer of (mostly) *Melaleuca nodosa* and *Melaleuca decora*, with low emergents of *Eucalyptus fibrosa* and *Eucalyptus parramattensis* subsp. *decadens*. Other areas form more of a forest structure where emergents of *Eucalyptus agglomerata* (atypical form) and *Eucalyptus resinifera* subsp. *resinifera* also occur, but still with the high abundance of *Melaleuca* species. These latter areas possibly represent transitional areas between this community and the Lower Hunter Spotted Gum–Ironbark Forest (Unit 1).

Within Werakata, this vegetation is restricted to localised patches associated with the Kurri Sand Swamp Woodland. It is not known how much of this vegetation type has been included in the mapping of Kurri Sands Swamp Woodland by NPWS (2000), but it is highly likely that it is poorly conserved in the region. As with the Kurri Sand Swamp Woodland [Unit 4], further survey and analysis of plot data is required from throughout the general Kurri Sands area to clarify floristic relationships. Additional areas are also desirable for addition to the reserve.

Central Hunter Riparian Forest [Unit 3]

Most major streams within Werakata support a vegetation type that is most closely identifiable with the Central Hunter Riparian Forest (NPWS 2000). However, there are several floristic differences worthy of mention. Along parts of Swamp Creek, such as in the Neath portion of the reserve, a deeply incised channel supports fringing *Casuarina glauca* with *Melaleuca styphelioides* and *Melaleuca linariifolia*, over an understorey which includes *Baumea juncea* and *Phragmites australis*. The presence of *Casuarina* and *Baumea* here suggests a strong saline influence not evident elsewhere in the reserve.

Other drainage lines (particularly Deadmans Creek) support *Eucalyptus canaliculata* and intergrades of this species with *Eucalyptus punctata*. The latter occurs sporadically in the open forests on slopes and ridges, but rarely occurs along creeklines. The presence of *Eucalyptus canaliculata* is also of some interest, as it is likely that populations here approach the southern distributional limit of the species (Hill 2002). According to Hill (2002), populations in the Maitland – Singleton – Cessnock area are intermediate between *Eucalyptus canaliculata* and *Eucalyptus punctata*.

Discussion

Comparison with REMS vegetation mapping

The finer scale of investigation possible in Werakata has greatly improved upon the regional LHCCREMS framework (NPWS 2000). The following points summarise these improvements:

- the Neath portion of the reserve is far more complex than the NPWS (2000) mapping indicates, which shows extensive areas of Lower Hunter Spotted Gum Ironbark Forest with a small incursion of the Kurri Sand Swamp Woodland in the north-east;
- the Bishops Hill portion is shown by NPWS (2000) to support considerably more of the Kurri Sands Swamp Woodland than is evident on the ground;
- small areas of heath and scrub have been omitted from the NPWS (2000) mapping, probably an artefact of the API process employed;
- in general, the distribution of Hunter Lowlands Redgum Forest throughout most of the reserve as shown in the NPWS (2000) mapping does not correspond with the ground situation, and this community is in fact restricted to the far north-western corner of the Bishops Hill portion.

The main consequences of this revised Werakata mapping are that there is considerably less Hunter Lowlands Redgum Forest present within conservation reserves than originally depicted by NPWS (2000), and the distribution of the *TSC Act*-defined Kurri Sands Swamp Woodland as mapped by NPWS (2000) misrepresents both the location and extent of this community within the reserve. Other communities likely to be restricted in distribution were not delineated by NPWS (2000); their full extent in the region is currently unknown.

Management issues

Fire has traditionally been a common feature of the bushland around Cessnock since European settlement, particularly in the last 100 years, and the current floristic compositions of the vegetation communities present are likely to reflect this history. Arson has been a continuing problem for many years due to the close proximity of urban Cessnock and it is probable that much of the area has been subjected to fire on average every 2–3 years. Fires occurred in several areas around Cessnock, including Werakata, during summer 2000–2001.

As a result of past forestry activities much of the vegetation of Werakata consists of regrowth trees. Public access was not restricted, and illegal rubbish dumping, trail bike riding and car dumping have occurred unabated for many years. Numerous trails and tracks are evident through Werakata; rationalisation of these should be undertaken to assist in the control of rubbish dumping, arson and weed dispersal. Trail-bike riding, a common occurrence in the Park, promotes erosion to fire trails and creates a generally inhospitable and noisy environment. Rubbish dumping and localised weed invasion from garden refuse is problematic in some areas. The high edge-to-area ratio for the reserve exacerbates these problems.

Recommendations

Considering the extent and distribution of vegetation communities and significant plant species present within the current boundaries of Werakata National Park, it is recommended that:

- investigation be carried out in areas around Cessnock for representative examples of the endangered Kurri Sand Swamp Woodland to add to the reserve network. These areas should encompass the variations in the community identified during this study and any others that become apparent. A wider survey of the entire Kurri Sands vegetation is warranted in order to more completely document the natural variation within this community.
- the poor conservation status of all other vegetation communities present within Werakata suggest that additional reservation is similarly required, as the reserve represents the only conservation reserve in the region supporting examples of most of these.
- additional reservation of the vulnerable *Eucalyptus parramattensis* subsp. *decadens* from around Cessnock be pursued, as current protection is unlikely to conserve more than 100 plants.
- more broadly, there is an opportunity for a comparative survey of all similar sand-based vegetation in the Sydney Basin, in order to synthesize and better understand the floristic relationships occurring within them.

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References

Belbin, L. (1991) The analysis of pattern in bio-survey data. Pp. 176–190. In *Nature Conservation: Cost Effective Biological Surveys and Data Analysis*. Ed. by C. Margules and M. Austin (CSIRO: Canberra).

Belbin, L. (1995a) *PATN Pattern Analysis Package: Users Guide* (CSIRO Division of Wildlife Rangelands Research: Canberra).

Belbin, L. (1995b) *PATN Pattern Analysis Package: Reference Manual* (CSIRO Division of Wildlife Rangelands Research: Canberra).

Bell, S. (1996) *Flora Survey and Assessment: Construction of Access Road to Proposed Extensions of Cessnock Landfill, Cessnock*. Ecotone Ecological Consultants Pty Ltd. Report to Maunsell Pty Ltd, February 1996.

Bell, S.A.J. (1998a) *Glenrock SRA and Awabakal NR vegetation survey. A fire management document*. Volumes 1 & 2. Eastcoast Flora Survey — Report to NSW National Parks and Wildlife Service (Hunter District) August 1998.

Bell, S.A.J. (1998b) *Lake Macquarie SRA, Pulbah Island NR, and Tingira Heights NR vegetation survey. A fire management document*. Volumes 1 & 2. Eastcoast Flora Surve, Report to NSW National Parks and Wildlife Service (Hunter and Central Coast Districts) April 1998.

Bell, S.A.J. (2000) *Validation survey of REMS mapping, Lower Hunter and Central Coast*. Undertaken for NSW National Parks and Wildlife Service, CRA Unit.

Bell, S.A.J. (2001a) *The vegetation of Werakata National Park, Hunter Valley, New South Wales*. Eastcoast Flora Survey: Report to NSW National Parks and Wildlife Service, Hunter Coast District.

Bell, S.A.J. (2001b) Notes on the distribution and conservation status of some restricted plant species from sandstone environments of the upper Hunter Valley, New South Wales. *Cunninghamia* 7(1): 77–88.

Bell, S.A.J. & Fallding, M. (2002.) *Tomago Sandbeds: Guidelines for weed and bushfire risk management*. Report to Department of Land and Water Conservation.

Bell, S. & Helman, A. (in prog.) *Distribution and habitat of* Macrozamia flexuosa *C. Moore in Lake Macquarie Shire*. Lake Macquarie Research Grant No. 99/00–2

Bell, S. & Murray, M. (2001) *The ecological significance of Bow Wow Creek Gorge, Mulbring, Hunter Valley, New South Wales: a nationally significant site*. Eastcoast Flora Survey & Forest Fauna Surveys P/L, Report to Cessnock City Council.

Binns, D. (1996) *Flora survey, Morisset Forestry District, Central Region, New South Wales*. Morisset Forestry District EIS Supporting Document No. 3. State Forests of NSW, Sydney.

Briggs, J.D. & Leigh, J.H. (1996) *Rare or Threatened Australian Plants* (CSIRO: Canberra).

Bureau of Meteorology (2001) Climatic data. [web site: www.bom.gov.au/climate/averages]

Cropper, S.C. (1993) *Management of Endangered Plants* (CSIRO Publications: East Melbourne).

EJE Group (1995) *Morisset EIS European cultural heritage study*. Morisset Forestry District environmental impact statement, supporting document No. 9. State Forests of NSW.

Fallding, M. & Bell, S. (1996) *Wollombi vegetation and habitat plan*. Land & Environment Planning, Report to Cessnock City Council.

Griffith, S.J., Wilson, R., & Maryott-Brown, K. (2000) Vegetation and flora of Booti Booti National Park and Yahoo Nature Reserve, lower North Coast of New South Wales. *Cunninghamia* 6(3): 645–715.

Harden, G.J. (1990–93) *Flora of New South Wales*. Volumes 1–4. (NSW University Press: Kensington)

Harden, G.J. (2002) *Flora of New South Wales*. Volume 2. Revised Edition. (NSW University Press: Kensington)

Harden, G.J. & Murray, L.J. (Eds) (2000) *Supplement to Flora of New South Wales Volume 1* (NSW University Press, Sydney).

Hill, K.D. (1998) Cycadophyta. *Flora of Australia* 48: 597–661.

Hill, K.D. (2002) *Eucalyptus*. Pp. 96–164 IN *Flora of New South Wales. Volume 2*. Revised Edition. (NSW University Press: Kensington)

Hill, K.D. & Stanberg, L.C. (2002) *Eucalyptus castrensis* (Myrtaceae), a new species from New South Wales. *Telopea* 9(4): 773–776.

Keith, D.A. (2000) Sampling designs, field techniques and analytical methods for systematic plant population surveys. *Ecological Management & Restoration* 1(2): 125–139.

Keith, D.A. & Bedward, M. (1999) Native vegetation of the South East Forests region, Eden, New South Wales. *Cunninghamia* 6(1): 1–218.

Kinhill Engineers Pty Ltd (1995) *Morisset Forestry District EIS. An assessment of Aboriginal archaeological sites*. Morisset Forestry District environmental impact statement, supporting document No. 8. State Forests of NSW.

Kovac, M. (1991) *Soil landscapes of the Singleton 1:250 000 sheet* (Soil Conservation Service of NSW: Sydney).[map]

Kovac, M. & Lawrie, J.W. (1991) *Soil landscapes of the Singleton 1:250 000 sheet* (Soil Conservation Service of NSW: Sydney). [report]

Makinson, G.J. (2002) *Grevillea*. Pp. 32–66 IN *Flora of New South Wales: Volume 2*. Revised Edition. G.J. Harden (Ed.) (NSW University Press: Kensington).

McGillivray, D.J. (2000) Proteaceae 2, Grevillea. *Flora of Australia 17A*: 1–460.

Murray, M., Bell, S., & Hoye, G. (2001) *Lower Hunter and Central Coast Flora and Fauna Survey Guidelines. Version 1.0*. Prepared for the Lower Hunter and Central Coast Regional Environmental Management Strategy.

National Parks and Wildlife Service (1999) *Forest ecosystem classification and mapping for the Hunter sub-region in the Lower North East Comprehensive Regional Assessment*. A project undertaken for the Joint Commonwealth NSW Regional Forest Agreement Steering Committee of the NSW Comprehensive Regional Assessments. Project Nos. NL 10/EH & NL 02/EH. CRA Unit, Sydney Zone NPWS. March 1999.

National Parks and Wildlife Service (2000) *Vegetation Survey, Classification and Mapping: Lower Hunter and Central Coast Region*. A project undertaken for the Lower Hunter and Central Coast Regional Environmental Management Strategy, CRA Unit, Sydney Zone NPWS. April 2000.

NSW Scientific Committee (1998) *Grevillea parviflora* subsp. *parviflora*. Final determination.

Olde, P.M. & Marriott, N.R. (1994) A taxonomic revision of *Grevillea arenaria* and *Grevillea obtusiflora* (Proteaceae: Grevilleoideae). *Telopea* 5 (4): 711–733.

Olde, P. & Marriott, N. (1995) *The Grevillea Book: Volume 3* (Kangaroo Press: Kenthurst).

Patrick, G. (1999) *Initial Flora Survey to Sample Potential habitat, Abundance and Distribution of the New Plant Species Persoonia 'North Rothbury'*. Report prepared for NSW National Parks and Wildlife Service. Ecotone Ecological Consultants.

Rasmus, P.L., Rose, D.M., & Rose, G. (1969) *Singleton 1:250 000 Geological Series (Sheet SI 56–1)*. First Edition. NSW Department of Mines.

Specht, R.L., Specht, A., Whelan, M.B., & Hegarty, E.E. (1995) *Conservation Atlas of Plant Communities in Australia*. (Centre for Coastal Management, Lismore, in association with Southern Cross University Press: Lismore)

Spencer, R.D. & Lumley, P.F. (2002) *Callistemon*. Pp. 193–198 IN *Flora of New South Wales Volume 2*. Revised Edition. Ed by G.J. Harden. (NSW University Press: Kensington)

Thackway, R. & Cresswell, I.D. (1995) (Eds) *An Interim Biogeographic Regionalisation for Australia: A Framework for Establishing the National System of Reserves*. Version 4 (Australian Nature Conservation Agency: Canberra).

Tozer, M. (2003) The native vegetation of the Cumberland Plain, western Sydney: systematic classification and field identification of communities. *Cunninghamia* 8(1): 1–75.

Walker, J. & Hopkins, M.S. (1990) Vegetation. Pp. 58–86 In: *Australian Soil and Land Survey Field Handbook*. Ed. by R. McDonald, R. Isbell, J. Speight, J. Walker and M. Hopkins (Inkata Press: Sydney).

Weston, P.H. (1999) *Persoonia pauciflora* (Proteaceae), a new species from the Hunter Valley, New South Wales. *Telopea* 8(2): 159–164.

Wilson, P., Gott, M., & Schofield, M.J. (1997) *Vegetation mapping guidelines for reserve and conservation planning*. NSW National Parks and Wildlife Service, Environmental Survey & Research Division. May 1997.

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Appendix 1. Species list – Werakata National Park

Plant taxa recorded from Werakata NP during 2000-2001, based on plot data. Species marked "*" represent exotic or introduced taxa. Vegetation communities have been listed for each taxa, as follows:

1 = Lower Hunter Spotted Gum – Ironbark Forest
2 = Central Hunter Riparian Forest
3 = Hunter Lowlands Redgum Forest
4 = Kurri Sand Swamp Woodland
5 = Kurri Sand Melaleuca Scrub-Forest
6 = Riparian Melaleuca Thicket

Ferns

ADIANTACEAE	
Adiantum aethiopicum	2
DENNSTAEDTIACEAE	
Pteridium esculentum	1 2 3 4

SINOPTERIDACEAE

Cheilanthes sieberi subsp. *sieberi*	1 2 3 4 5

Cycads

ZAMIACEAE

Macrazamia flexuosa	1 2 5
Macrazamia reducta	1

Dicotyledons

ACANTHACEAE

Pseuderanthemum variabile	1 2 3 4 5

APIACEAE

Hydrocatyle peduncularis	2 3 6
Platysace ericoides	4
Platysace lanceolata	2 4 5

ARALIACEAE

Astratricha obovata	1 4 5

ASTERACEAE

Brachycome multifida var. *multifida*	1 3
Chrysacephalum semipapposum	1 3
Euchiton (Gnaphalium) sphaericum *	1 2 3
Helichrysum scorpioides	1
Olearia ramulosa	1
Ozothamnus diasmifolius	1 4 5
Senecia madagascariensis *	1 2 3
Taraxacum officinale *	1 2 3
Vernania cinerea var. *cinerea*	1 2 3

CAMPANULACEAE

Wahlenbergia communis	1 4 5
Wahlenbergia gracilis	1 4 5

CASUARINACEAE

Casuarina glauca	2

CELASTRACEAE

Maytenus silvestris	1 3 4

CONVOLVULACEAE

Dichandra repens	2 3 6
Polymeria calycina	1 2 3

DILLENIACEAE

Hibbertia acicularis	1 4 5
Hibbertia aspera	1 4
Hibbertia diffusa	2 3
Hibbertia linearis	2 4
Hibbertia pedunculata	4
Hibbertia vestita	4

DROSERACEAE

Drosera auriculata	2

EPACRIDACEAE

Astroloma humifusum	1 4 5
Leucopogan virgatus	4
Lissanthe strigosa subsp. *strigasa*	1 4 5
Melichrus procumbens	4
Melichrus urceolatus	1 4 5
Monotoca scoparia	4 5
Styphelia triflora	1 4 5

EUPHORBIACEAE

Glochidion ferdinandi var. *ferdinandi*	1 6
Phyllanthus gasstroemii	2 3 6
Phyllanthus hirtellus	1 4 5
Phyllanthus virgatus	3

FABACEAE: Faboideae

Bossiaea heterophylla	4
Bossiaea obcordata	4
Daviesia genistifolia	1 4 5
Daviesia ulicifolia	1 4
Desmadium varians	2 3
Dillwynia retarta	4 5
Glycine clandestina	1 2 3 4 5
Glycine microphylla	2 3
Gamphalobium uncinatum	1 4 5
Hardenbergia violacea	1 2 3 4 5
Havea linearis	4 5
Mirbelia pungens	4
Mirbelia rubiifolia	4 5
Oxylobium pulteneae	1 4 5
Padolobium ilicifolium	1 4
Pultenaea cunninghamii	1
Pultenaea villasa	2 3

FABACEAE: Mimosoideae

Acacia brownii	1 4 5
Acacia buxifolia subsp. *buxifalia*	1 4 5
Acacio deanei subsp. *deanei*	2 3
Acacia elongata var. *elangata*	4 5
Acacia folcata	1 5
Acacia irrorota subsp. *irrorata*	1 5
Acacia linifolia	1 4
Acacia longifolia	1 2 3
Acacio ulicifolia	1 4 5

GOODENIACEAE

Dampiera stricta	4
Gaadenia heteraphylla subsp. *heteraphylla*	1 4 5
Gaadenia ratundifolia	1 4 5

HALORAGACEAE

Ganocarpus tetragynus	1 3 4 5
Halaragis heterophylla	2 3 6

LAURACEAE

Cassytha glabello forma *globella*	1 2 3 4 5

LOBELIACEAE

Pratia purpurascens	1 2 3 6

LORANTHACEAE

Amyema goudichaudii	1 2
Dendrophthoe vitellina	1 3 4 5

MYRSINACEAE

Rapanea voriabilis	2 3

MYRTACEAE

Angaphora bakeri	4 5
Angophora flaribunda	2 3
Babingtonia (Baeckea) pluriflara	2
Callistemon linearifolius	1 3
Callistemon linearis	1 4 5
Carymbia eximia	1
Carymbia gummifera	4 5
Carymbia maculata	1
Eucalyptus agglomerato	1 4 5
Eucalyptus amplifolia subsp. *amplifalia*	3
Eucalyptus canaliculato	2
Eucalyptus capitellata	1
Eucalyptus crebra	1
Eucalyptus fibrosa	1 5
Eucalyptus glaucina	1
Eucalyptus glaboidea	1 2
Eucalyptus maluccana	2

Eucalyptus parramattensis subsp. *decadens*	4 5
Eucalyptus punctata	1
Eucalyptus resinifera subsp. *resinifera*	4
Eucalyptus siderophloia	1
Eucalyptus tereticornis	3 6
Leptospermum parvifolium	1 4 5
Leptospermum polygalifolium subsp. *cismontanum*	1 4 5
Leptospermum trinervium	4 5
Melaleuca decora	1 5
Melaleuca linariifolia	2 3 6
Melaleuca nodosa	1 2 3 4 5
Melaleuca sieberi	4 5
Melaleuca styphelioides	2 6
Melaleuca thymifolia	4 5
Syncarpia glomulifera	1 2

OLEACEAE

Notelaea longifolia forma *longifolia*	1 3

OXALIDACEAE

Oxalis chnoodes	2 3
Oxalis perennans	1 2 3 5

PITTOSPORACEAE

Billardiera scandens var. *scandens*	1 2 3 4 5
Bursaria longisepala var. *longisepala*	1 5
Bursaria spinosa var. *spinosa*	1 5
Pittosporum revolutum	2 3

PLANTAGINACEAE

Plantago debilis	2 3

POLYGALACEAE

Comesperma sphaerocarpum	4

PROTEACEAE

Banksia oblongifolia	4 5
Banksia spinulosa var. *collina*	4
Grevillea montana	1 3 4 5
Grevillea parviflora subsp. *parviflora*	1 5
Hakea dactyloides	4 5
Hakea sericea	1 4 5
Isopogon anemonifolius	4
Lambertia formosa	4
Persoonia linearis	1 3 4 5

RUBIACEAE

Opercularia diphylla	1 2 3
Opercularia hispida	2 3
Pomax umbellata	1 3 4 5

RUTACEAE

Correa reflexa var reflexa	1 4 5

SANTALACEAE

Exocarpos cupressiformis	1 3
Exocarpos strictus	1 4

THYMELIACEAE

Pimelea linifolia subsp. *linifolia*	4

VIOLACEAE

Viola hederacea	2 3 6

Flowering Plants

Monocotyledons

ANTHERICACEAE

Caesia parviflora var. *parviflora*	1 4 5
Laxmannia gracilis	1 4 5

COMMELINACEAE

Murdannia graminea	2 3

CYPERACEAE

Baumea juncea	2
Carex appressa	2 3 6
Fimbristylis dichotoma	2 3
Gahnia aspera	2 3
Gahnia radula	1 5
Lepidosperma gunnii	1
Lepidosperma laterale	1 3 4 5

HYPOXIDACEAE

Hypoxis hygrometrica var. *hygrometrica*	2 3

IRIDACEAE

Patersonia sericea	4

LOMANDRACEAE

Lomandra confertifolia subsp. *pallida*	1 4 5
Lomandra cylindrica	1 3 4 5
Lomandra filiformis subsp. *coriaceae*	4 5
Lomandra filiformis subsp. *filiformis*	1 4 5
Lomandra glauca	4 5
Lomandra longifolia	2 3 6
Lomandra multiflora subsp. *multiflora*	1 2 3

ORCHIDACEAE

Acianthus fornicatus	2 3
Pterostylis acuminata	2

PHORMIACEAE

Dianella caerulea var. *caerulea*	1 4 5
Dianella caerulea var. *cinerascens*	1
Dianella prunina	1 5
Dianella revoluta var. *revoluta*	1 3 5

POACEAE

Anisopogon avenaceus	1 4 5
Aristida ramosa var. *ramosa*	1 2 3 5
Aristida vagans	1 2 3 4
Aristida warburgii	4 5
Austrodanthonia longifolia	1 3 4 5
Austrodanthonia tenuior	13 4
Austrostipa verticillata	2 3
Axonopus affinis *	2 3
Cymbopogon refractus	1 5
Dichelachne micrantha	1 4 5
Digitaria ramularis	1 4 5 6
Echinopogon caespitosus var. *caespitosus*	1 3 5
Echinopogon ovatus	1 2 3 4 5
Entolasia marginata	2 3
Entolasia stricta	1 2 3 4 5
Eragrostis brownii	2 3 4 5
Imperata cylindrica var. *major*	1 3 4 5
Joycea pallida	1 4 5
Microlaena stipoides var. *stipoides*	1 2 3 6
Panicum simile	1 4 5
Paspalidium criniforme	3
Paspalidium distans	1 2 3 4
Phragmites australis	2
Poa sieberiana var. *sieberiana*	1 3
Setaria gracilis *	2 3
Sorghum leiocladum	2 3
Themeda australis	1 2 3 4 5

XANTHORRHOEACEAE

Xanthorrhoea glauca subsp. *glauca*	4 5

Total taxa: 191

Appendix 2: Vegetation community profiles

Vegetation community profiles have been developed for Werakata National Park, and are based on detailed survey and mapping work and/or reconnaissance. Communities have been delineated using the PATN Analysis Package (Belbin 1995a, 1995b), supported by ground truthing. The following points should be noted in regard to the information presented in these profiles:

Community name: where possible, community names have been chosen in keeping with those applied during the Lower Hunter and Central Coast REMS study (NPWS 2000).

REMS Classification: equivalent community names using the REMS classification (NPWS 2000) are included to enable consistency with this regional work.

Description: structural and floristic information is based on survey site data sheets and field reconnaissance, and presents the typical and most characteristic species for that community.

Rare and Threatened Species: known occurrences of rare or threatened plant species within a particular community are listed.

Relationship to other communities: factors linking a particular vegetation community to other related communities are detailed, together with the major separating features between these communities.

Distribution: the distribution of each community is provided in two categories within Werakata NP, and in other areas outside of it but within the LHCC region. Also provided in this section are indications of the determining factors in the community's distribution, and the reliability of mapping for that community and potentially included units.

Conservation significance: the conservation significance of each vegetation community is provided at a Local, Regional and National level, based on currently available information and local knowledge. Only proclaimed conservation reserves are included. Local significance refers to a 50 km radius around the Cessnock area; Regional significance to the Sydney Basin biogeographical region of Thackway and Cresswell (1995), while National significance is largely based on Specht et al. (1995). In some cases, insufficient information is available to place communities within a conservation context. These instances are prefixed '?' to indicate uncertainties.

Threats: potential or currently known threats are listed for each community, particularly where these may be controlled in some way to prevent deleterious effects on the community.

Other comments: any further comments considered relevant to particular communities are included in this section, such as the incidence of weed species, variations within a community.

Lower Hunter Spotted Gum–Ironbark Forest (Unit 1)

REMS Classification: *Lower Hunter Spotted Gum–Ironbark Forest (MU 17)*

Description **No of Plots: 13**
Lower Hunter Spotted Gum-Ironbark Forest represents a vegetation type characterised by Spotted Gum (*Corymbia maculata*) and various Ironbarks (predominantly *Eucalyptus fibrosa*). In the Cessnock area, other canopy species include *Eucalyptus agglomerata* (atypical form), and in some exposed locations *Corymbia eximia*. Historically, this vegetation type has been heavily logged or cleared throughout the lower Hunter Valley, and consequently canopy and understorey composition has been altered. Dominance by *Melaleuca nodosa* in the shrub layer is one indication of past disturbance.

Structure
Tree: 8–25 m, 20–40% cover. Small tree: 3–12 m, 5–40% cover. Tall shrub: 2–4 m, 5–40% cover. Shrub: 0.5–2 m, 20–60% cover. Ground: < 0.5 m, 20–40% cover.

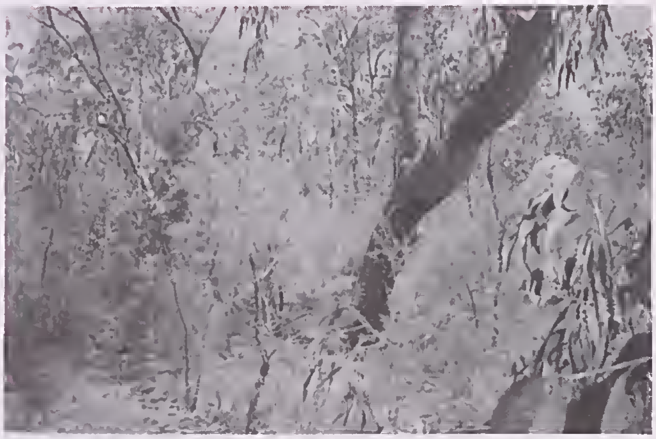

Fig. 4. *Corymbia eximia* dominated woodland within the Lower Hunter Spotted Gum – Ironbark Forest (Unit 1).

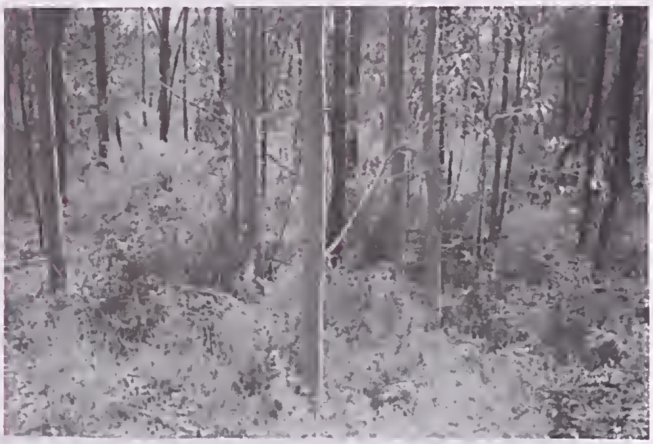

Fig. 5. Lower Hunter Spotted Gum – Ironbark Forest (Unit 1), showing even-aged regrowth stands of *Corymbia maculata* and *Eucalyptus fibrosa*.

Floristics
Trees: *Corymbia maculata, Eucalyptus fibrosa, Eucalyptus agglomerata* (atypical form). *Corymbia eximia.*
Small trees: *Bursaria spinosa.*
Shrubs: *Grevillea montana, Daviesia ulicifolia, Bursaria longisepala* var. *longisepala, Lissanthe strigosa, Acacia elongata* var. *elongata, Astrotricha obovata, Melaleuca nodosa, Grevillea parviflora* subsp. *parviflora, Persoonia linearis, Leptospermum parvifolium, Isopogon anemonifolius, Podolobium ilicifolium, Acacia buxifolia, Hakea sericea, Syncarpia glomulifera* subsp. *glomulifera* (shrub form), *Dillwynia retorta, Acacia ulicifolia.*
Vines: *Cassytha glabella forma glabella, Hardenbergia violacea, Glycine clandestina.*
Herbs: *Platysace ericoides, Phyllanthus hirtellus forma A, Pomax umbellata, Goodenia rotundifolia, Hibbertia vestita, Gompholobium uncinatum, Oxylobium pulteneae.*
Graminoids: *Entolasia stricta, Aristida vagans, Dichelachne micrantha, Dianella revoluta* var. *revoluta, Eragrostis brownii, Panicum simile, Poa sieberiana* subsp. *sieberiana, Austrodanthonia longifolia, Lomandra filiformis* subsp. *coriacea, Imperata cylindrica* var. *major, Joycea pallida, Lomandra multiflora* subsp. *multiflora, Lomandra cylindrica, Lomandra confertifolia* subsp. *pallida, Lomandra filiformis* subsp. *filiformis, Anisopogon avenaceus, Themeda australis*
Ferns: *Cheilanthes sieberi* subsp. *sieberi*
Sedges: *Lepidosperma laterale*
Cycads: *Macrozamia flexuosa, Macrozamia reducta*

Rare or Threatened Species
NSW TSC Act species: *Grevillea parviflora* subsp. *parviflora*.
Rare species: *Grevillea montana*, *Macrozamia flexuosa*

Relationship to other communities
The characteristic presence of *Corymbia maculata* and *Eucalyptus fibrosa* in the canopy clearly distinguish this type from all other communities in the Park. In areas where the canopy is low, there may be some confusion with the Kurri Sand Melaleuca Scrub-Forest (Unit 5), particularly in those areas where broad ecotones exist. In addition, areas with a disturbance history tend to support dense thickets of *Melaleuca nodosa* in the understorey, which again can be difficult to distinguish. In these cases, separation of the two communities is probably best achieved based on structure.

Distribution within Werakata NP
This vegetation type represents the most widespread community in the Park, and covers sizeable areas of the Kitchener, Abermain and Bishops Hill portions, and is also represented in the Neath portion to a lesser degree. 1600 ha of this vegetation type currently lies within the Park.

Outside Werakata NP
Lower Hunter Spotted Gum–Ironbark Forest is relatively widespread throughout the central and lower Hunter Valley areas, although many areas have been cleared or modified. This type merges with the Coastal Foothills Spotted Gum-Ironbark Forest in the Quorrobolong area. NPWS (2000) have mapped 26 917 ha of this type within the region.

Determining factors
Within Werakata, this vegetation type occurs on Permian-based yellow-brown or grey-brown clay soils on most ridges and slopes.

Mapping reliability and included units
Mapped from aerial photographic interpretation and field reconnaissance, and considered accurate. There may be some inclusion of Kurri Sand Melaleuca Scrub-Forest (Unit 5) in some areas where a broad ecotonal zone exists.

Conservation significance
Local: Poor (Werakata NP). Regional: Poor (no reservation known). National: Poor (No reservation known).

Threats
Fire: Inappropriate fire regimes may adversely affect this community, with frequent (<3 years) firing dramatically simplifying understorey vegetation.

Other comments
On some exposed crests where sandstone outcropping occurs, species such as *Corymbia eximia*, *Isopogon anemonifolius*, and *Acacia buxifolia* form a variation of the typical form of this community. Although survey was undertaken here, sufficient distinction could not be made to lift this variant to community status.

Central Hunter Riparian Forest (Unit 2)

REMS Classification: *? Central Hunter Riparian Forest (MU 13)*

Description No of Plots: 2

Central Hunter Riparian Forest is a variable community occupying narrow zones along tributaries of the major creeks in the Park. Within the region this vegetation type has been largely disturbed or infiltrated with weed species. In Werakata, dominant canopy species include *Eucalyptus canaliculata*, *Angophora floribunda*, *Casuarina glauca* (in places), and various *Melaleuca* species. This vegetation most closely associates with the Central Hunter Riparian Forest as defined by NPWS (2000), although some floristic differences are apparent.

Structure
Tree: 10–25 m, 20–40% cover. Small tree: 8–10 m, 0–20% cover. Tall shrub: 4–6 m, 60–70% cover. Shrub: 0.5–3 m. 5–30% cover. Ground: < 0.5 m, 90–100% cover.

Floristics
Trees: *Angophora floribunda*, *Eucalyptus canaliculata*, *Eucalyptus moluccana*. *Eucalyptus fibrosa*, *Eucalyptus tereticornis*.
Small trees: *Melaleuca decora*. *Melaleuca styphelioides*, *Melaleuca linariifolia*, *Acacia irrorata* subsp. *irrorata*. *Casuarina glauca*.
Shrubs: *Bursaria longisepala* var. *longisepala*, *Lissanthe strigosa*, *Grevillea montana*, *Exocarpus strictus*, *Acacia longifolia*, *Bursaria spinosa*, *Melaleuca nodosa*, *Babingtonia pluriflora*
Vines: *Glycine clandestina*, *Glycine microphylla*, *Cassytha glabella forma glabella*.
Herbs: *Hibbertia linearis*, *Lomandra longifolia*, *Pomax umbellata*, *Pratia purpurascens*, *Oxalis perennans*, *Pseuderanthemum variabile*, *Plantago debilis*, *Gonocarpus tetragynus*.
Graminoids: *Themeda australis*, *Imperata cylindrica* var. *major*, *Aristida vagans*, *Dianella revoluta* var. *revoluta*, *Dichelachne micrantha*, *Austrodanthonia tenuior*, *Poa sieberiana* subsp. *sieberiana*, *Dianella caerulea* var. *cinerascens*, *Echinopogon ovatus*, *Eragrostis brownii*, *Austrostipa verticillata*, *Aristida ramosa* var. *ramosa*, *Sorghum leiocladum*, *Phragmites australis*, *Microlaena stipoides* var. *stipoides*, *Cymbopogon refractus*, *Entolasia marginata*, *Digitaria ramularis*, *Echinopogon caespitosus* var. *caespitosus*.
Ferns: *Cheilanthes sieberi* subsp. *sieberi*, *Adiantum aethiopicum*, *Pteridium esculentum*.
Sedges: *Gahnia aspera*, *Baumea juncea*, *Lepidosperma laterale*.
Cycads: *Macrozamia flexuosa*.

Rare or Threatened Species
Rare species: *Grevillea montana*, *Macrozamia flexuosa*.

Relationship to other communities
Central Hunter Riparian Forest is closely related to the Hunter Lowlands Redgum Forest (Unit 3), through a sharing of canopy species such as *Eucalyptus tereticornis*, *Eucalyptus moluccana*, and *Angophora floribunda*, and several understorey species. However, Unit 3 generally does not support *Casuarina glauca* and *Eucalyptus canaliculata*, and occurs on flats and drainage depressions (not riparian zones). The levels of past disturbance shown in areas supporting both of these communities makes differentiation difficult. In Unit 3, redgum species (*Eucalyptua amplifolia* subsp. *amplifolia*, *Eucalyptus tereticornis*, *Eucalyptus glaucina*) clearly dominant, while these species are rare or absent in the Central Hunter Riparian Forest.

Distribution within Werakata NP
This vegetation type occurs along Swamp Creek in the Neath portion, Deadman's Creek in the Bishops Hill portion, and other minor creeks in the Abermain and Kitchener portions of the Park. 77 ha of this vegetation type currently lies within the Park.

Outside Werakata NP
Central Hunter Riparian Forest is relatively uncommon in the region, with most occurrences being heavily disturbed or modified through agricultural practices. NPWS (2000) have mapped 1187 ha of this vegetation type in the region, with only 5 ha in reserve.

Determining factors
This vegetation type occurs as a fringing community along the banks of major streams, generally in areas of high exposure (flat to gently undulating land) on Permian clays.

Mapping reliability and included units
Mapped from aerial photographic interpretation and field reconnaissance, and considered reasonably accurate.

Conservation significance
Local: Poor (Werakata NP). Regional: Poor (no reservation known). National: Poor (no reservation known).

Threats
Upstream processes: this vegetation type is likely to be sensitive to upstream disturbances such as erosion and water pollution, which allow the introduction of exotic plant species.

Other comments

The narrow bands of this community occurring along parts of Swamp Creek are in excellent condition. In these areas, the occurrence of *Casuarina glauca* and *Baumea juncea*, species normally associated with estuarine environments, are of particular botanical and conservation interest.

Hunter Lowlands Redgum Forest (Unit 3)

REMS Classification: *Hunter Lowlands Redgum Forest (MU 19)*

Description No of Plots: 1

In the far north-western corner of the Bishops Hill portion of the Park, a small area of Hunter Lowlands Redgum Forest occurs on a gentle flat adjacent to Deadman's Creek. The majority of this has been grazed in the past, and consequently the understorey has been reduced largely to grasses and herbs with scattered shrubs. Outside of the Park, this vegetation does not appear as disturbed and supports a denser understorey. Redgums (*Eucalyptus amplifolia* subsp. *amplifolia*, *Eucalyptus tereticornis*, *Eucalyptus glaucina*) characterise this community, with other species such as *Eucalyptus crebra*, *Eucalyptus moluccana*, and *Angophora floribunda* also present.

Structure

Tree: 18–20 m, 40–50% cover. Tall shrub: 3–6 m, 5–15% cover. Shrub: 1–2 m, 5–40% cover. Ground: < 0.5 m, 80–90% cover.

Floristics

Trees: *Eucalyptus amplifolia* subsp. *amplifolia*, *Eucalyptus tereticornis*, *Eucalyptus glaucina*, *Eucalyptus crebra*, *Eucalyptus moluccana*, *Angophora floribunda*.
Small trees: *Melaleuca decora*, *Acacia irrorata* subsp. *irrorata*.
Shrubs: *Exocarpus strictus*, *Grevillea montana*, *Callistemon linearis*, *Acacia ulicifolia*, *Pultenaea cunninghamii*, *Daviesia ulicifolia*, *Melaleuca nodosa*.
Vines: *Cassytha glabella forma glabella*.
Herbs: *Hypoxis hygrometrica* var. *hygrometrica*, *Helichrysum scorpioides*, *Vernonia cinerea* var. *cinerea*, *Pratia purpurascens*, *Desmodium varians*, *Laxmannia gracilis*, *Dichondra repens*, *Pomax umbellata*, *Polymera calycina*, *Opercularia hispida*, *Hibbertia linearis*, *Murdannia graminea*, *Goodenia rotundifolia*, *Haloragis heterophylla*, *Phyllanthus virgatus*, *Oxalis perennans*, *Hydrocotyle peduncularis*.
Graminoids: *Microlaena stipoides* var. *stipoides*, *Aristida vagans*, *Eragrostis brownii*, *Paspalidium distans*, *Echinopogon ovatus*, *Entolasia stricta*, *Austrodanthonia longifolia*, *Dianella caerulea* var. *caerulea*, *Lomandra confertifolia* subsp. *pallida*, *Panicum simile*
Ferns: *Cheilanthes sieberi* subsp. *sieberi*.
Sedges: *Fimbrostylis dichotoma*, *Lepidosperma laterale*.

Rare or Threatened Species

NSW TSC Act species: *Eucalyptus glaucina*. Rare species: *Grevillea montana*.

Relationship to other communities

Hunter Lowlands Redgum Forest is closely related to the Central Hunter Riparian Forest (Unit 2), through a sharing of canopy species such as *Eucalyptus tereticornis*, *Eucalyptus moluccana*, and *Angophora floribunda*, and several understorey species. However, Unit 2 generally also includes *Casuarina glauca* and *Eucalyptus canaliculata*, and is restricted to immediate riparian zones (not flats and drainage depressions). The levels of past disturbance shown in areas supporting both of these communities makes differentiation difficult. In the Hunter Lowlands Redgum Forest, redgum species (*Eucalyptus amplifolia* subsp. *amplifolia*, *Eucalyptus tereticornis*, *Eucalyptus glaucina*) clearly dominant, while these species are rare or absent in Unit 2.

Distribution within Werakata NP

This vegetation type occurs only adjacent to Deadman's Creek in the north-western corner of the Bishops Hill portion of the Park, where it occupies approximately 7 ha.

Outside Werakata NP

NPWS (2000) have mapped 4856 ha of their Hunter Lowlands Redgum Forest (MU 19) remaining in the region, with only 100 ha in reserve. This vegetation type as described by NPWS (2000) appears to be highly variable and difficult to define in some places.

Determining factors

Hunter Lowlands Redgum Forest occurs in open depressions and drainage flats on clay-based Permian Sediments, adjacent to relatively minor creeklines.

Mapping reliability and included units

Mapped from aerial photographic interpretation and field reconnaissance, and considered reasonably accurate. Boundaries can be difficult to define in areas where it merges with the surrounding Lower Hunter Spotted Gum–Ironbark Forest (Unit 1).

Conservation significance

Local: Poor (Werakata NP). Regional: Poor (no reservation known). National: Poor (no reservation known).

Threats

Grazing and clearing of this community has historically occurred throughout its range, and these threats remain where areas lie adjacent to agricultural lands.

Other Comments

The area supporting this vegetation type adjacent to Deadmans Creek supports an apparently isolated population of the vulnerable *Eucalyptus glaucina*.

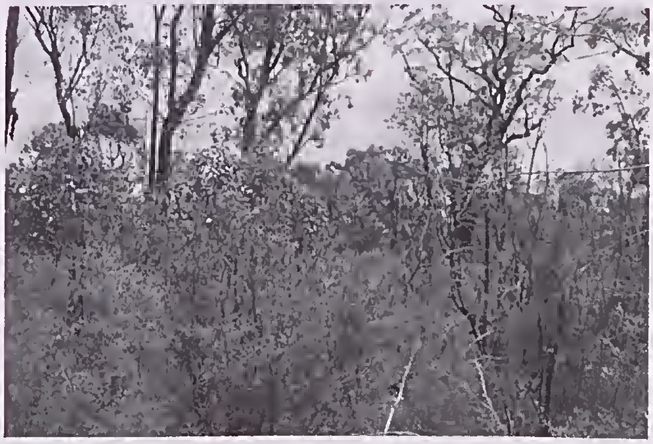

Fig. 6. Kurri Sand Swamp Woodland (Unit 4), dominated by *Angophora bakeri*.

Kurri Sand Swamp Woodland (Unit 4)

REMS Classification: *Kurri Sand Swamp Woodland (MU 35)*

Description No of Plots: 3

Small areas within Werakata support vegetation having close affinities to the Kurri Sand Swamp Woodland (Unit 35) described by NPWS (2000), although significant differences in floristic composition are evident. In these areas, the canopy is dominated by *Angophora bakeri*, *Eucalyptus resinifera* subsp. *resinifera*, and *Eucalyptus agglomerata* (atypical form), with *Eucalyptus parramattensis* subsp. *decadens* and *Corymbia gummifera* occasionally present. Understorey vegetation is dominated by a range of shrubs typical of sand environments, but with clay species such as *Melaleuca nodosa* also prominent in some parts.

Structure

Tree: 5–12 m, 10–40% cover. Tall shrub: 1.5–3 m, 10–80% cover. Shrub: 0.5–1.5 m, 20–70% cover. Ground: < 0.5 m, 10–60% cover.

Floristics

Trees: *Angophora bakeri, Eucalyptus resinifera* subsp. *resinifera, Eucalyptus agglomerata* (atypical form), *Eucalyptus parramattensis* subsp. *decadens, Corymbia gummifera.*
Small trees: *Melaleuca sieberi, Melaleuca decora.*
Shrubs: *Banksia oblongifolia, Banksia spinulosa* var. *collina, Dillwynia retorta, Leptospermum trinervium, Acacia ulicifolia, Leptospermum polygalifolium* subsp. *cismontanum, Leucopogon virgatus, Isopogon anemonifolius, Bossiaea heterophylla, Monotoca scoparia, Melaleuca nodosa, Lambertia formosa, Melichrus procumbens, Hakea dactyloides, Melaleuca thymifolia, Exocarpus strictus, Hakea sericea, Callistemon linearis, Styphelia triflora, Leptospermum parvifolium, Hibbertia acicularis.*
Vines: *Cassytha glabella forma glabella, Mirbelia rubifolia.*
Herbs: *Platysace ericoides, Dampiera stricta, Drosera auriculata, Hibbertia vestita, Helicrysum scorpioides.*
Graminoids: *Lomandra cylindrica, Lomandra glauca, Anisopogon avenaceus, Entolasia stricta, Aristida warburgii, Eragrostis brownii, Xanthorrhoea glauca* subsp. *glauca.*
Sedges *Gahnia radula, Lepidosperma gunnii.*
Orchids: *Acianthus fornicatus.*

Rare or Threatened Species

NSW TSC Act species: *Eucalyptus parramattensis* subsp. *decadens*

Relationship to other communities

Kurri Sand Swamp Woodland is distinctly different to all other vegetation within Werakata. The canopy combination of *Angophora bakeri, Eucalyptus resinifera* subsp. *resinifera*, and *Eucalyptus agglomerata* (atypical form) does not occur in other communities. *Eucalyptus parramattensis* subsp. *decadens* also occurs in Kurri Sand Melaleuca Scrub-Forest (Unit 5), but the very dense shrub layer of *Melaleuca nodosa*, and the absence of other key species (eg: *Angophora bakeri, Lambertia formosa, Leptospermum trinervium, Banksia spinulosa* var. *collina*) separates the two. In places in Unit 5, *Eucalyptus resinifera* subsp. *resinifera* co-dominates with *Eucalyptus agglomerata* (atypical form), but again the understorey composition separates the two.

Distribution within Werakata NP

This vegetation type occurs predominantly in the Neath portion of the Park, although the Bishops Hill portion also supports small areas. 70 ha of this vegetation type has been mapped.

Outside Werakata NP

NPWS (2000) have indicated that 2195 ha of their Kurri Sand Swamp Woodland (MU 35) remains in the region, and they map only 46 ha in reserve (ie: Werakata NP). This figure should now be amended to 70 ha. This vegetation type is restricted to the Kurri–Cessnock–Maitland area.

Determining factors

Kurri Sand Swamp Woodland occurs on level to slightly undulating sand deposits where drainage is relatively free-flowing.

Mapping reliability and included units

This community has been mapped from aerial photographic interpretation and field reconnaissance, and is considered accurate.

Conservation significance

Local: Poor (Werakata NP). Regional: Poor (no reservation known). National: Poor (no reservation known).

Threats

Fire: Frequent fire regimes may dramatically alter the current floristic composition of this community.

Other comments

Vegetation within this community does not conform readily to that described by NPWS (2000), but does lie broadly within its bounds. Soil drainage within this type dictates the floristic composition of differing stands. In some areas where soils are particularly clayey, understorey vegetation is dominated by *Melaleuca nodosa*. In more sandy areas, this species is far less prominent and *Leptospermum trinervium* and *Leptospermum polygalifolium* dominate. Outside of the current Park boundaries, considerable areas of Kurri Sand Swamp Woodland (NPWS-mapped) occur. Further acquisition of lands supporting all forms of this vegetation type is recommended.

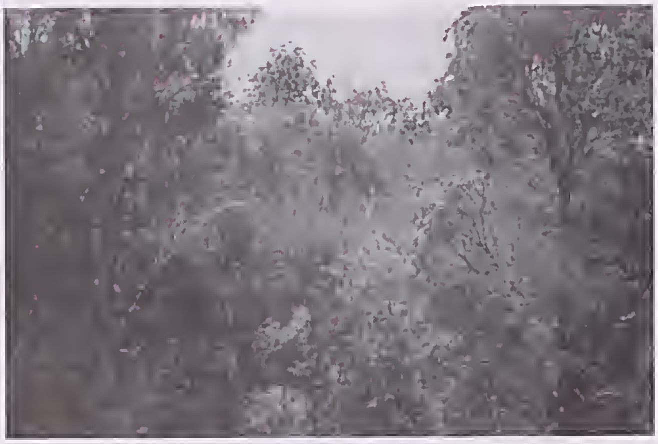

Fig. 7. Kurri Sand Melaleuca Scrub-Forest (Unit 5), showing *Melaleuca decora* and *Melaleuca nodosa*, and low emergent *Eucalyptus fibrosa* and *Eucalyptus parramattensis* subsp. *decadens.*

Kurri Sand Melaleuca Scrub-Forest (Unit 5)

REMS Classification: *? Kurri Sand Swamp Woodland (MU 35)*

Description No of Plots: 2

Kurri Sand Melaleuca Scrub-Forest represents a vegetation type not delineated during the regional modelling process (NPWS 2000), but related to the Kurri Sand Swamp Woodland as identified there. It is characterised by dense stands of Melaleuca (*Melaleuca nodosa, Melaleuca decora*) with stunted emergents of mostly *Eucalyptus fibrosa* and *Eucalyptus parramattensis* subsp. *decadens* (variant 5a). In places, this vegetation type conforms to a forest structure where *Eucalyptus agglomerata* (atypical form) and *Eucalyptus resinifera* subsp. *resinifera* co-dominate with occasional *Eucalyptus fibrosa, Eucalyptus sideroploia*, and *Eucalyptus parramattensis* subsp. *decadens* (variant 5b). Most areas supporting this vegetation type are found in close proximity to Kurri Sand Swamp Woodland (Unit 4), and it is thought that clay deposits associated with the Kurri Sands determine its distribution.

Structure

Tree: 3–15 m, 5–20% cover. Small tree: 3–8 m, 30-40% cover. Tall shrub: 2–4 m, 5–15% cover. Shrub: 0.5–2 m, 60–100% cover. Ground: < 0.5 m, 5–60% cover.

Floristics

Small trees: *Eucalyptus fibrosa, Eucalyptus parramattensis* subsp. *decadens, Eucalyptus agglomerata* (atypical form), *Eucalyptus crebra* (extreme north), *Melaleuca decora, Eucalyptus resinifera* subsp. *resinifera.*
Shrubs: *Melaleuca nodosa, Melaleuca thymifolia, Callistemon linearis, Isopogon anemonifolius, Leucopogon virgatus, Lissanthe strigosa, Leptospermum parvifolium, Dillwynia retorta, Astroloma humifusum, Acacia ulicifolia, Hakea sericea, Astrotricha obovata, Hibbertia acicularis, Pultenaea cunninghamii, Bursaria longisepala* var. *longisepala, Grevillea montana, Banksia spinulosa* var. *collina.*
Vines: *Cassytha glabella forma glabella.*
Herbs: *Phyllanthus hirtellus forma A, Mirbelia pungens, Platysace ericoides, Goodenia rotundifolia, Hibbertia vestita, Drosera auriculata, Pratia purpurascens.*
Graminoids: *Aristida ramosa* var. *ramosa, Lomandra cylindrica, Anisopogon avenaceus, Entolasia stricta, Aristida vagans, Dianella*

revoluta var. *revoluta, Panicum simile, Lomandra filiformis* subsp. *coriacea, Eragrostis brownii, Imperata cylindrica* var. *major, Paspalidium distans.*
Ferns: *Cheilanthes sieberi* subsp. *sieberi.*
Sedges: *Gahnia radula, Lepidosperma gunnii, Lepidosperma laterale.*
Cycads: *Macrozamia flexuosa.*
Orchids: *Pterostylis sp.*

Rare or Threatened Species
NSW TSC Act species: *Eucalyptus parramattensis* subsp. *decadens, Callistemon linearifolius.* Rare species: *Grevillea montana, Macrozamia flexuosa.*

Relationship to other communities
Kurri Sand Melaleuca Scrub-Forest is most closely related to the Lower Hunter Spotted Gum–Ironbark Forest (Unit 1) and the Kurri Sand Swamp Woodland (Unit 4), through a sharing of often dense stands of *Melaleuca nodosa.* However, Unit 1 can be separated by the presence of a taller canopy of *Corymbia maculata* with *Eucalyptus fibrosa*, and a variety of understorey species, while Unit 4 is characterised by *Angophora bakeri, Eucalyptus resinifera* subsp. *resinifera*, and *Corymbia gummifera* occurring with *Eucalyptus parramattensis* subsp. *decadens* in the canopy. As well, a number of understorey species normally associated with sand environments are present.

Distribution within Werakata NP
Small pockets of the scrub variant (5a) of this vegetation type occur in the Neath and Bishops Hill portions of the Park, normally associated with Kurri Sand Swamp Woodland (Unit 4). The forest variant (5b) occurs only in the Neath portion. 183 ha of sub-unit 5a, and 80 ha of sub-unit 5b, currently lie within the Park.

Outside Werakata NP
NPWS (2000) have not identified this vegetation type, but indicate that 2195 ha of their Kurri Sand Swamp Woodland (MU 35) remains in the region, with only 46 ha in reserve (i.e. Werakata NP). It is possible that this vegetation type includes the Kurri Sand Melaleuca Scrub-Forest, and it is probably also restricted to the Kurri–Cessnock–Maitland area.

Determining factors
Kurri Sand Melaleuca Scrub-Forest occurs on poorly drained clay deposits associated with the Kurri Sands. In most cases, these deposits comprise compacted clay soil with some laterite, which influences local floristic composition. Other smaller areas occur on shallow drainage lines with similar soil conditions.

Mapping reliability and included units
Mapped from aerial photographic interpretation and field reconnaissance, and is considered accurate.

Conservation significance
Local: Poor (Werakata NP). Regional: Poor (no reservation known). National: Poor (no reservation known).

Threats:
No threats have been identified for this community.

Other comments
In the extreme northern part of the Bishops Hill portion, emergent *Eucalyptus crebra* is found in this community, and understorey diversity is generally also higher. The forest variant (5b) described for the Neath portion may represent a distinct community, but further sampling and analysis is required. In their regional study, NPWS (2000) do not identify Kurri Sand Melaleuca Scrub-Forest, although there are strong similarities to similar *Melaleuca nodosa* thickets from the Wyong sub-coastal plain.

Riparian Melaleuca Thicket (Unit 6)

REMS Classification: *? Central Hunter Riparian Forest (MU 13)*

Description No of Plots: [none]

Along some drainage lines on Permian clays where drainage is impeded, narrow bands of *Melaleuca linariifolia* occur, forming dense thickets. Other species present in the small tree layer include *Melaleuca styphelioides* and occasionally *Callistemon salignus.* Emergent trees may include *Eucalyptus tereticornis, Angophora floribunda* or *Eucalyptus canaliculata.* Understorey vegetation is generally limited to sedges such as *Carex appressa* and occasional grasses.

Structure
Trees: 15–25 m, 10–25% cover. Small tree: 5–12 m, 80–100% cover. Ground: < 0.8m, 80–100% cover.

Floristics
Trees: *Eucalyptus tereticornis, Angophora floribunda, Eucalyptus canaliculata.*
Small trees: *Melaleuca linariifolia, Melaleuca styphelioides.*
Vines: *Parsonsia straminea.*
Graminoids: *Carex appressa, Entolasia marginata.*

Rare or Threatened Species
None recorded.

Relationship to other communities
Riparian Melaleuca Thicket is generally quite distinct and should not be confused with any other community. The dominance of dense stands of *Melaleuca linariifolia* are characteristic, and these are best developed in poorly drained areas where runoff collects after rain events. Characteristics of Central Hunter Riparian Forest (Unit 2) are similar, but that community can be distinguished on a structural (forest) and floristic (higher species diversity) basis.

Distribution within Werakata NP
This vegetation type occurs intermittently along drainage lines throughout the Park, where drainage is poor. Best development is in the Abermain portion near the disused dump site. Less than 5 ha of this vegetation type is likely to occur within the Park.

Outside Werakata NP
This vegetation type does not readily align with any of the REMS vegetation communities. However, it is likely to form part of the Central Hunter Riparian Forest (MU13), of which NPWS (2000) have mapped 1187 ha remaining in the region.

Determining factors
This vegetation type occurs only on impeded clay soils, with areas of standing water after rain events.

Mapping reliability and included units
Riparian Melaleuca Thicket has not been mapped individually due to the small size of stands and the difficulty of detecting these on the available aerial photographs. Consequently, this unit is included in the mapping of Central Hunter Riparian Forest (Unit 2). Mapping of known stands may be carried out in the future.

Conservation significance
Local: Poor (Werakata NP). Regional: Poor (no reservation known). National: Poor (no reservation known).

Threats
No threats have been identified for this community.

Other comments
Detailed survey is yet to be undertaken for this vegetation type, and the information presented here is based on brief field notes. It is possible that this community forms a variant of the Central Hunter Riparian Forest (Unit 2) occurring on impeded clay soils, but is recognised here as distinct due to its characteristic and unmistakable composition.

Fire response syndromes of shrubs in grassy woodlands in the New England Tableland Bioregion

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Abstract: In fire-prone grassy woodlands, fire response and time to reach reproductive maturity are two traits that can be used to provide an indication of the minimum interval between fires needed to maintain biodiversity. This study examined the effects of fire intensity and adult size on shrub mortality together with the primary and secondary juvenile periods of shrub species in the New England Tableland (NET) Bioregion. Most shrub species resprouted via basal lignotubers following fire, irrespective of fire intensity and shrub size. The primary juvenile period of most species was found to be greater than four years and the secondary juvenile period for most resprouting species was less than four years. These results suggest that a minimal interval between fires of eight years may be needed to maintain shrub species in grassy woodlands in the NET Bioregion, and that repeated fires at intervals of less than 8 years should be avoided. The time taken for shrubs in the grassy woodlands of the NET Bioregion to reach reproductive maturity appears to be longer than conspecifics in other Bioregions. Caution is needed when using data collected from outside a Bioregion to determine minimum fire frequency thresholds.

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Introduction

Knowledge of how plant species respond to fire regimes is fundamental for management of biodiversity. In fire-prone communities, studies of the fate of the standing population, and of the time taken to reach reproductive maturity post-fire, are of two-fold importance. Firstly, when no quantitative data are available about the effects of different fire regimes on communities, species attributes can be used to predict qualitative changes in species composition (Noble & Slatyer 1980). Secondly, the continued study of factors affecting the post-fire survival of populations can be used to build on current models.

The fire response of an individual plant will either be death or survival and at a population level this dichotomy is often applied to describe species that survive fire (resprouters) and those killed by fire (obligate seeders). In reality, however, a continuum from 0–100% mortality of individuals within a population exists among species (Morrison 1995, Bond & Van Wilgen 1996, Morrison & Renwick 2000). Characteristics of a particular fire, distribution of size-classes and the physiological and anatomical features of a species will affect the percentage mortality of a population post-fire (Whelan 1995). Bond and Van Wilgen (1996) formalised size-specific post-fire survivorship into four survival curves. In summary, the first group (type I) acquires fire-tolerance quickly, and has little post-seedling mortality; the second group (type II) becomes increasingly fire-tolerant with increasing size; the third group (type III) attains fire-tolerance during juvenile stages, but loses fire-tolerance with age, and the final group (type IV) are those species that never attain fire-tolerance (obligate seeders). Knowledge of patterns of fire-tolerance and percentage mortality in different size-classes allows greater understanding of how species will react under different fire regimes, especially when communities are dominated by species that resprout.

The time taken to reach reproductive maturity following fire is important for both obligate seeders and resprouters, as it is directly related to generation length and will affect the capacity of a population to increase in size (Whelan 1995). The length of the primary juvenile period (the time taken to reach reproductive maturity from seed) is particularly important for obligate seeders as population decline or local extinction could potentially occur if the interval between fires is shorter than the time taken to reach reproductive maturity and to accumulate an adequate seedbank (Cary & Morrison 1995, Keith 1996). The time taken for resprouting individuals to flower is referred to as the secondary juvenile period. Population decline may occur if the time between fires is less than the secondary juvenile period of resprouters, particularly those species that do not generally display 100% post-fire survival (Keith 1996). Age at first reproduction has been found to vary among species within a community (Benson 1985, Bradstock & O'Connell 1988), between populations (Benson 1985) and between individuals within a population (Carthew 1993). Resprouting species generally take longer to flower from seed than obligate seeding species (Abbott 1985, Bell 2001). The secondary juvenile period of resprouters, however, tends to be shorter than the primary juvenile period for resprouters and obligate seeders (Zammit & Westoby 1987).

Knowledge of the fate of the standing population and the time to reach reproductive maturity after a fire event has increased steadily over the past decade for many community types in Australia. However, little is known about the fire ecology of woody plants in grassy woodlands in eastern Australia (see review by Clarke 2000). In particular there is a dearth of knowledge about the shrub species occurring in the cool temperate regions in the New England Tableland Bioregion of northern NSW (NET Bioregion). Some fire response and maturation observations from coastal grassy communities have been made but it is not known if it is appropriate to extrapolate data from conspecifics in different climates for use in fire management planning.

This study addresses four questions: (i) Which species resprout following fire and where does resprouting arise? (ii) Does plant size influence post-fire survival for those species that show some degree of resprouting? (iii) Does fire intensity affect mortality for those species that show some degree of resprouting? (iv) What is the length of the primary and secondary juvenile periods of shrub species in grassy woodlands?

Methods

Study area

The New England Tableland Bioregion (NET Bioregion) covers 3 004 080 ha., about 40% of which, native vegetation remains (National Land & Water Resources Audit 2001). About 7.5% of extant native vegetation is within conservation reserves (Benson 1999). Grassy woodlands once covered extensive areas of the NET Bioregion (Benson & Ashby 2000) but, have been extensively cleared for pastoralism. Remnant patches of grassy woodland occur in conservation reserves, travelling stock reserves, roadside reserves and on private land. Clarke (2003) demonstrated that under pastoralism, shrub abundances decline, although the herbaceous layer remains relatively intact.

Fire response studies were conducted in two grassy woodland conservation areas: Imbota Nature Reserve and Booroolong Nature Reserve. Imbota Nature Reserve (218 ha in size) is 10 km SE of Armidale (National Parks & Wildlife Service 2001). The average maximum temperature in January (summer) in Armidale is 27.1°C, while the average minimum temperature in July (winter) is 0.3°C. Average yearly rainfall is 790 mm. Areas at Imbota NR where experimental burns were conducted ranged from 1010–1040 m elevation. Experimental burns were conducted in areas with yellow podzolic soils and metasediment lithology on sites that were generally flat or with a slight to medium slope. The last recorded fire in Imbota NR was a small fire in 1969; no records exist for the fire history before this (National Parks & Wildlife Service 2001). Vegetation structure at Imbota NR ranges from woodland to low open forest with a sparse understorey of shrubs and a near-continuous herbaceous layer. The dominant tree species in the study sites were *Eucalyptus blakelyi, Eucalyptus bridgesiana, Eucalyptus caliginosa, Eucalyptus melliodora* and *Eucalyptus viminalis*. The dominant species in the herbaceous layer were *Poa sieberiana* var. *sieberiana* and *Themeda australis*.

Booroolong Nature Reserve (865 ha in size) is 30 km NW of Armidale (National Parks & Wildlife Service 2002). No specific data are available on the climate of Booroolong Nature Reserve, although the climate is similar to that of nearby Guyra, average maximum temperature in January (summer) is 24.6°C; average minimum temperature in July (winter) is 0.6°C, average yearly rainfall is 884 mm). Areas burnt in experimental fires ranged from 1290–1310 m elevation, on yellow podsolic soils, overlying a metasediment lithology. The areas were generally flat or had a slight to medium slope. No fires have been recorded at Booroolong NR for the past 20 years (National Parks & Wildlife Service 2002) and the area may not have been burnt for more than 50 years, based on the lack of fire scars. Vegetation structure at Booroolong NR ranges from woodland to open forest with a sparse to medium density of shrubs in the understorey and a dense herbaceous layer. The dominant tree species in the study sites were *Eucalyptus caliginosa, Eucalyptus dalrympleana* subsp. *heptantha, Eucalyptus laevopinea* and *Eucalyptus radiata. Poa sieberiana* var. *sieberiana* and *Themeda australis* were common in the herbaceous layer.

Fire response traits of shrub species

The fire response of shrub species was determined following three experimental burns at each Nature Reserve. Experimental burning occurred at Imbota NR in Spring 1999, and at Booroolong NR in Autumn 2000. Each burn site was approximately 50 × 50 m and had an average fine fuel load of approximately 8 tonnes/ ha. Before each fire, fine fuel (straw) was added to half the area of each burn site in order to increase the fuel loads to at least 16 tonnes/ ha so as to determine the effects of different fire intensities on plant mortality. Recording the intensity of fires is inherently difficult (Whight & Bradstock 1999) and intensity was not measured in the current study as the rate of spread could not be determined due to the way the fires were lit (along control lines and then burnt towards the centre). Kitchin (2001) used comparable fuel loads to that in the high fuel load areas of this study, and achieved fires of moderate intensity, indicating that moderate intensity and low intensity fires would have been expected in our high fuel load and low fuel load areas respectively.

Shrubs were tagged before each fire within each burn area, and in adjacent unburnt areas, and the size (measured as basal girth) of individuals was recorded. Three years after the fire individuals were assessed for evidence of resprouting, and the position of resprouting noted. Species were classified as obligate seeders when less than 30% of individuals survived 100% leaf scorch, and as resprouters when more than 70% of individuals survived 100% leaf scorch (Gill & Bradstock 1992).

Table 1. The post-fire response, method of resprouting of shrub species examined. For survival, numbers are the percentage survival (sample size). n.a. indicates that the life-history trait is not applicable as this species is an obligate seeder.

Species	Fire response	Survival %		Mode of resprouting
Acacia buxifolia subsp. *buxifolia*	resprouter	100	(6)	basal/lignotuber
Acacia dealbata	obligate seeder	0	(3)	n.a.
Acacia filicifolia	resprouter	78	(23)	suckers/epicormic
Acacia implexa	resprouter	100	(11)	suckers/basal
Acacia ulicifolia	obligate seeder	0	(9)	n.a.
Brachyloma daphnoides subsp. *glabrum*	resprouter	100	(4)	basal/lignotuber
Cassinia leptocephala	obligate seeder	0	(3)	n.a.
Cassinia quinquefaria	obligate seeder	21	(29)	n.a.
Cryptandra amara	resprouter	100	(5)	basal/lignotuber
Daviesia latifolia	resprouter	100	(2)	basal/lignotuber
Epacris microphylla	resprouter	100	(4)	basal/lignotuber
Hardenbergia violacea	resprouter	100	(10)	basal/lignotuber
Hibbertia acicularis	resprouter	100	(23)	basal/lignotuber
Hibbertia obtusifolia	resprouter	100	(47)	basal/lignotuber
Hovea heterophylla	resprouter	100	(3)	basal/lignotuber
Indigofera adesmiifolia	resprouter	100	(5)	basal/lignotuber
Indigofera australis	resprouter	100	(16)	basal/lignotuber
Jacksonia scoparia	resprouter	100	(5)	suckers
Leucopogon sp. nov	resprouter	100	(2)	basal/lignotuber
Leucopogon lanceolatus var. *lanceolatus*	resprouter	100	(7)	basal/lignotuber
Lissanthe strigosa subsp. *strigosa*	resprouter	100	(57)	basal/lignotuber
Lomatia silaifolia	resprouter	100	(5)	basal/lignotuber
Melichrus urceolatus	resprouter	100	(46)	basal/lignotuber
Monotoca scoparia	resprouter	100	(18)	basal/lignotuber
Olearia myrsinoides	resprouter	100	(15)	basal/lignotuber
Olearia sp. aff. *elliptica*	resprouter	70	(10)	basal/lignotuber
Olearia viscidula	resprouter	78	(33)	basal/lignotuber
Pimelea linifolia	resprouter	100	(3)	basal/lignotuber
Pultenaea microphylla	resprouter	100	(10)	basal/lignotuber
Pultenaea setulosai	resprouter	100	(12)	basal/lignotuber
Rhytidosporum diosmoides	resprouter	100	(3)	basal/lignotuber

Primary juvenile and secondary juvenile periods

Observations on primary and secondary juvenile periods were made in August 2002 and September 2003. Data for the primary juvenile period of species were collected from naturally recruiting populations and from seed sown in the field for another study. Shrubs were examined for evidence that they had reached reproductive maturity at a number of burn sites with different times-since-fire. At Imbota NR, three sites were 3 years post-fire, three sites were 2.5 years post-fire, three sites were 2 years post-fire and three sites were 1.5 years post-fire, when sampled in 2002. At Booroolong NR, three sites were 2.5 years post-fire, three sites were 2 years post-fire and three sites were 1.5 years post-fire when sampled in 2002.

Data analyses

Formal data analyses were only undertaken for species that displayed some variation in post-fire mortality. Plant mortality at the two different fire intensities was compared using analyses of deviance (with a binomial error structure) using GLMStat (Beath 2001). The relationship between plant mortality and plant size was investigated by assigning individuals to one of three size-classes based on stem diameter before fire (small: 0–10 cm, medium: 11–20 cm, and large: > 21 cm diameter) and analyses of deviance (with a binomial error structure) using GLMStat (Beath 2001).

Results

Post-fire response of species and location of dormant buds

Of 31 shrub species recorded (Table 1) 27 species classified as resprouters, including 24 species exhibiting 100% survival. Four species were classified as obligate seeders — *Acacia dealbata*, *Acacia ulicifolia*, *Cassinia leptocephala* and *Cassinia quinquefaria*. No mortality of individuals outside the burn areas was recorded.

All but three resprouting species resprouted exclusively from basal (lignotuberous) buds. *Jacksonia scoparia* and *Acacia implexa* resprouted via root suckers and *Acacia filicifolia* resprouted via root suckers and epicormic buds.

Achieving 100% leaf scorch of the mat-forming shrub *Pultenaea microphylla* proved difficult as the dense prostrate plant appears to be nearly fire resistant. With increased fuel loads, 100% leaf scorch was induced and resprouting from the lignotuber occurred.

Effects of fire intensity and plant size on mortality

Formal analysis was conducted on only those species that displayed variation in mortality — *Acacia filicifolia*, *Cassinia quinquefaria* and *Olearia viscidula* (*Olearia* sp. aff. *elliptica* did display some variation in mortality, but too few individuals were available to examine the effects of plant size

Table 2. The post-fire response time to flowering of shrub species examined. * Indicates that no data are available. n.a. indicates that the life-history trait is not applicable as this species is an obligate seeder

Species	Fire response	Primary juvenile period	Secondary juvenile period
Acacia buxifolia subsp. *buxifolia*	resprouter	*	Not flowering after 3.5 years
Acacia dealbata	obligate seeder	Not flowering after 4 years	n.a.
Acacia filicifolia	resprouter	Not flowering after 4 years	Not flowering after 4 years
Acacia implexa	resprouter	*	Not flowering after 4 years
Acacia ulicifolia	obligate seeder	3 years	n.a.
Brachyloma daphnoides subsp. *glabrum*	resprouter	*	2.5 years
Cassinia leptocephala	obligate seeder	Not flowering after 4 years	n.a.
Cassinia quinquefaria	obligate seeder	*	n.a.
Cryptandra amara	resprouter	*	3 years
Daviesia latifolia	resprouter	Not flowering after 4 years	Not flowering after 4 years
Epacris microphylla	resprouter	*	Not flowering after 3.5 years
Hakea eriantha	resprouter	Not flowering after 4 years	*
Hakea laevipes subsp. *graniticola*	resprouter	Not flowering after 4 years	*
Hardenbergia violacea	resprouter	4 years	3 years
Hibbertia acicularis	resprouter	*	3 years
Hibbertia obtusifolia	resprouter	*	Not flowering after 3 years
Hovea heterophylla	resprouter	*	2.5 years
Indigofera adesmiifolia	resprouter	*	Not flowering after 4 years
Indigofera australis	resprouter	4 years	1.5 years
Jacksonia scoparia	resprouter	*	Not flowering after 4 years
Leucopogon sp. nov	resprouter	*	< 3 years
Leucopogon lanceolatus var. *lanceolatus*	resprouter	Not flowering after 4 years	Not flowering after 3.5 years
Lissanthe strigosa subsp. *strigosa*	resprouter	*	< 1.5 years
Lomatia silaifolia	resprouter	*	Not flowering after 3.5 years
Melichrus urceolatus	resprouter	*	< 1.5 years
Monotoca scoparia	resprouter	*	< 1.5 years
Olearia myrsinoides	resprouter	*	< 1.5 years
Olearia sp. aff. *elliptica*	resprouter	Not flowering after 4 years	2 years
Olearia viscidula	resprouter	*	2 years
Pimelea linifolia	resprouter	*	3 years
Pultenaea microphylla	resprouter	*	3 years
Pultenaea setulosai	resprouter	*	3 years
Rhytidosporum diosmoides	resprouter	*	< 1.5 years

and fire intensity). Neither fire intensity nor plant size significantly affected mortality of *Acacia filicifolia* ($F_{1,4}$ = < 0.001, $P > 0.05$; $F_{3,3}$ = 2.29, $P > 0.05$) or *Olearia viscidula* ($F_{1,4}$ = 0.123, $P > 0.05$; $F_{2,3}$ = 1.77, $P > 0.05$). For *Cassinia quinquefaria*, fire intensity did not significantly affect survival ($F_{1,4}$ = 6.67, $P > 0.05$), but plant size did significantly affect mortality, with the smallest plants having greatest survivorship ($F_{3,5}$ = 14.02, $P < 0.01$).

Primary and secondary juvenile periods of a selection of shrub species

Acacia ulicifolia (primary juvenile period 3 years), *Indigofera australis* (4 years) and *Hardenbergia violacea* (4 years) were the only species that had a primary juvenile period of four years or less (Table 2). Other species examined were not flowering and evidently have a primary juvenile period greater than four years though how long is unknown. Most resprouting species were found to have a secondary juvenile period of less than four years (Table 2).

Discussion

Fire response of species and the influence of fire intensity and plant size on mortality

The majority of species in this study was found to resprout after fire, with basal resprouting being the most common regeneration mode. Most resprouting species exhibited 100% survival, and neither fire intensity nor initial size of plants was found to influence mortality of most species. These results differ from previous studies where mortality within a species has been found to be influenced by fire intensity and plant size (e.g. Moreno & Oechel 1993, Morrison & Renwick 2000). Plant mortality within a species may increase with fire intensity, especially in the smallest size-classes (Morrison & Renwick 2000). The lack of a relationship between size and mortality may be due to all individuals being of roughly equivalent age or at least having had ample time to develop fire-tolerance. If germination events for shrub species generally occur after fire, then only a few individuals in the smallest size-classes would be expected in this study as fire is thought to have been excluded from both reserves for more than 30 years.

Few studies have examined the percentage post-fire survival of co-occurring species in Australian vegetation communities and of those, few have found such a preponderance of species with 100% post-fire survival (i.e. type 1 species as defined by Bond & Van Wilgen 1996). Hodgkinson (1998) examined shrub species in semi-arid woodlands of NSW and found survival ranged from 18–90%. Similarly, in open forests in the Sydney region, shrubs and small trees ranged from 0–83% survival under low intensity fires and 0–27% survival under high intensity fires (Morrison & Renwick 2000).

Our findings are consistent with a previous landscape scale study in the NET Bioregion (Clarke & Knox 2002) that found 81% of grassy woodland shrub species had a resprouting fire response. Clarke and Knox (2002) found grassy woodlands and wet heaths to have a higher proportion of resprouters than in shrubby forest communities. Various models were examined to account for these patterns although none was able to account for landscape scale differences in resprouting. An interesting feature of the mode of resprouting in our study was the prevalence of species with basal resprouting compared with epicormic shooting. Bellingham and Sparrow (2000) have suggested that such patterns are a result of selection under frequent intense disturbance. This theory needs to be tested by obtaining better information on the disturbance frequencies in grassy woodlands, although this may be difficult to reconstruct given the fragmented nature of grassy woodland in the present landscape.

Post-fire flowering

The primary juvenile period of most species was found to be greater than four years, conversely, the secondary juvenile period was generally found to be less than four years, results consistent with previous studies (e.g. Zammit & Westoby 1987).

There is limited but growing knowledge about the length of the primary juvenile period for Australian species, and the primary juvenile period of some of the species in the current study has been recorded elsewhere. The primary juvenile period of *Hardenbergia violacea* has been recorded as one year in the Sydney Region (Benson & McDougall 1996); in the current study, it was four years. Wark (1997) found the primary juvenile period of *Indigofera australis* to be two years in Victoria, but in the current study it appears to be more than four years. These differences may be related to climate, with the NET Bioregion experiencing a shorter growing season, and plants taking longer to reach reproductive maturity. This suggestion seems reasonable, as many obligate seeders within shrubby woodlands of the NET Bioregion have primary juvenile periods of greater than 5 years (Clarke, unpublished data). Caution is needed when using data about reproductive periods from different Bioregions.

Most of the shrubs in this study had a secondary juvenile period of less than four years and are similar to a range of shrub species within shrubby woodlands in the NET Bioregion (Clarke, unpublished data).

Management implications

Results from this study can be used to formulate a baseline for the minimum fire interval for grassy woodlands in the NET Bioregion. The primary juvenile period is a particularly important life-history attribute of obligate seeders, as population decline may occur if the interval between fires is shorter than the time taken to reach reproductive maturity. The primary juvenile period for most obligate seeders in this study was found to be greater than 4 years, suggesting that population decline will occur in the grassy woodlands if the interval between successive fires is less than 5 years. Keith et al. (2002) recommended that the minimum threshold in fire frequency should also include three reproductive seasons, in order to accumulate an adequate seedbank. The minimum threshold for these woodlands would therefore be a fire-free interval of 8 years. However the minimum threshold is likely to be greater than 8 years, as it is not known when the obligate seeders will reach reproductive maturity; continued monitoring in the future is necessary. The maximum fire-free period could not be determined from this study as data on the longevity of shrubs were not collected. However the very low densities of shrubs in remnant sites may reflect the exclusion of fire from some of these areas for more than 50 years. Hence the upper limit for exclusion of fire may be in the order of 20–40 years, for species which have fire-dependent germination cues.

One species, *Acacia filicifolia*, was found to have less than 100% post-fire survival, and a secondary juvenile period greater than 4 years. These results suggest that unless some inter-fire intervals are greater than the time taken for *Acacia filicifolia* to re-reach reproductive maturity (secondary juvenile period) then population decline might occur.

The historic fire regimes of grassy woodlands are poorly known and are difficult to reconstruct (Lunt 2002). There is a dearth of contemporary and historic data on fire regimes in the NET Bioregion. Benson and Ashby (2000) suggested that grassy woodlands of the NET Bioregion were subjected to relatively frequent burning by Aboriginal people, though, given the length of primary juvenile periods for obligate seeders in our study, a history of high fire frequency is unlikely for these places. In addition a field survey of the distribution and abundance of shrub species across the region showed that obligate seeding species were present in 60% of the sites (Knox, unpublished data) suggesting that inter-fire intervals were not generally shorter than 8 years.

For better management of shrub species in the remaining vestiges of the NET Bioregion grassy woodlands, further quantification of primary juvenile periods and fire responses for a broader range of species, including the rare and threatened taxa, is needed. Season of burn may also affect mortality in a population and this factor needs to be examined experimentally. Studies of the effects of fire regimes on other life history stages are also needed to develop a clear understanding of population dynamics of shrubs under different fire regimes. Finally, to test suggested minimal fire frequency thresholds in these woodlands, manipulative landscape studies of the effects of different fire regimes are needed.

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References

Abbott I. (1985) Reproductive ecology of *Banksia grandis* (Proteaceae). *New Phytologist* 99: 129–148.

Beath K.J. (2001) *GLMStat User Manual Version 5.5*. Sydney, Australia.

Bell D.T. (2001) Ecological response syndromes in the flora of south-western Western Australia: fire resprouter versus reseeders. *The Botanical Review* 67: 417–440.

Bellingham P.J. & Sparrow A.D. (2000) Resprouting as a life history strategy in woody plant communities. *Oikos* 89: 409–416.

Benson D. & McDougall L. (1996) Ecology of Sydney plant species part 4: Dicotyledon family Fabaceae. *Cunninghamia* 4: 553–746.

Benson D.H. (1985) Maturation periods for fire-sensitive shrub species in Hawkesbury sandstone vegetation. *Cunninghamia* 1: 339–349.

Benson J.S. (1999) *Setting the scene: The native vegetation of New South Wales. Background Paper No. 1*. Native Vegetation Advisory Council, Sydney.

Benson J.S. & Ashby E.M. (2000) Vegetation of the Guyra 1: 100 000 map sheet New England Bioregion, New South Wales. *Cunninghamia* 6: 747–872.

Bond W.J. & Van Wilgen B.W. (1996) *Fire and Plants* (Chapman & Hall: London).

Bradstock R.A. & O'Connell M.A. (1988) Demography of woody plants in relation to fire: *Banksia ericifolia* L.f. and *Petrophile pulchella* (Schrad) R. Br. *Australian Journal of Ecology* 13: 505–518.

Carthew S.M. (1993) Patterns of flowering and fruit production in a natural population of *Banksia spinulosa*. *Australian Journal of Botany* 41: 465–480.

Cary G.J. & Morrison D. A. (1995) Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: combinations of inter-fire intervals. *Australian Journal of Ecology* 20: 418–426.

Clarke P.J. (2000) Plant population processes in temperate woodlands of eastern Australia — premises for management. In *Temperate eucalypt woodlands in Australia : biology, conservation, management and restoration*. Hobbs R. J. and Yates C. J. (Eds). (Surrey Beatty and Sons: Chipping Norton NSW) pp. 248–270.

Clarke P. J. (2003) Composition of grazed and cleared temperate grassy woodlands in eastern Australia: patterns in space and inferences in time. *Journal of Vegetation Science* 14: 5–14.

Clarke P. J. & Knox K. J. E. (2002) Post-fire response of shrubs in the tablelands of eastern Australia: do existing models explain habitat differences? *Australian Journal af Botany* 50: 53–62.

Gill A. M. & Bradstock R. A. (1992) A national register for the fire responses of plant species. *Cunninghamia* 2: 653–660.

Hodgkinson K.C. (1998) Sprouting success of shrubs after fire — height dependent relationships for different strategies. *Oecologia* 115: 64–72.

Keith D. (1996) Fire-driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. *Proceedings of the Linnean Society of N.S.W* 116: 37–78.

Keith D.A., Williams J.E. & Woinarski C.Z. (2002) Fire management and biodiversity conservation: key approaches and principles. In *Flammable Australia: the fire regimes and biodiversity of a continent*. Bradstock R.A., Williams J.E. & Gill A. M. (Eds) (Cambridge University Press: Cambridge, New York) pp. 401–425.

Kitchin M.B. (2001) *Fire ecology and fire management for the conservation of plant species and vegetation communities in a National Park in Northern NSW, Australia*. PhD Thesis, University of New England.

Lunt I.D. (2002) Grazed, burnt and, cleared: how ecologists have studied century-scale vegetation changes in Australia. *Australian Journal of Botany* 50: 391–407.

Moreno J.M. & Oechel W.C. (1993) Demography of *Adenostoma fasciculatum* after fires of different intensities in southern California chaparral. *Oecologia* 96: 95–101.

Morrison D.A. (1995) Some effects of low-intensity fires on populations of co-occurring small trees in the Sydney region. *Proceedings of the Linnean Society of NSW* 115: 109–119.

Morrison D.A. & Renwick J.A. (2000) Effects of variation in fire intensity on regeneration of co-occurring species of small trees in the Sydney region. *Australian Journal of Botany* 48: 71–79.

National Land & Water Resources Audit (2001) *Australian Native Vegetation Assessment 2001*. National Land and Water Resources Audit, ACT.

National Parks & Wildlife Service (2001) *Imbota Nature Reserve Draft Plan of Management*. Unpublished Report, NSW National Parks and Wildlife Service.

National Parks & Wildlife Service (2002) *Booroolong Nature Reserve Draft Plan of Management*. Unpublished Report, NSW National Parks & Wildlife Service.

Noble, I.R. & Slatyer, R.O. (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* 43: 5–21.

Wark M.C. (1997) Regeneration of some forest and gully communities in the Angahook-Lorne State Park (north-eastern Otway Ranges) 1–10 years after the wildfire of February 1983. *Proceedings of the Royal Society of Victoria* 109: 7–36.

Whelan R. J. (1995) *The ecology of fire* (Cambridge University Press: Cambridge).

Whight S. & Bradstock R. (1999) Indices of fire characteristics in sandstone heath near Sydney, Australia. *International Journal of Wildland Fire* 9: 145–153.

Zammit C. & Westoby M. (1987) Seedling recruitment strategies in obligate-seedling and resprouting *Banksia* shrubs. *Ecology* 68: 1984–1992.

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A regional examination of the mistletoe host species inventory

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Abstract: Downey (1998) collated an inventory of mistletoe host species based on herbaria records for every aerial mistletoe species (families Loranthaceae and Viscaceae) in Australia. In this paper the representative nature of those host lists is examined in an extensive field survey of mistletoes and their host species in south-eastern New South Wales (including Australian Capital Territory). Four new host species not in the 1998 inventory, and eight new mistletoe-host combinations (i.e. a previously recorded host but not for that particular mistletoe species) were collected. These new records were distributed throughout the survey area. Interestingly, these new host-mistletoe combinations were for mistletoe species that were well represented in the national inventory (i.e. with many herbarium collections and numerous host species). The initial inventory was incomplete. at least for south-eastern New South Wales, indicating the need for (i) more targeted surveys similar to this one, and/or (ii) regular updates of the host inventory based on voucher specimens. A possible reasons why information on host-mistletoe combinations is incomplete may be that such combinations may be dynamic (i.e. mistletoe species may be expanding their suite of potential hosts, either fortuitously or as result of evolutionary pressures).

***Cunninghamia* (2004) 8(3): 354–361**

Introduction

Hemi-parasitic mistletoes are often considered to be host-specific i.e. certain mistletoe species occur on a select range of host species (Kuijt 1969, Barlow & Wiens 1977, Barlow 1981, Atsatt 1983, Reid et al. 1995, Norton & de Lange 1999). The term low host specificity has been used to describe mistletoe species which have many unrelated host species, and the term high host specificity when mistletoe species are restricted to one or a few related host species (Barlow & Wiens 1977, Atsatt 1983). Host specificity implies a one-way interaction, that of the mistletoe. The role the host plays in this parasitic interaction is rarely considered to be important, implying the host has no or little influence on the parasitic process. However, the host can play a role in determining its parasitic constituents, through host resistance to haustorial penetration (Kuijt 1969, Hariri et al. 1987, Yan 1993) and chemical incompatibility (Kuijt 1969). There is a considerable number of plant species which are not host species, other than the obvious herbaceous and annual species, which are incapable of sustaining mistletoes due to their growth forms and size (i.e. Downey (1998) only recorded 873 host species of an Australian vascular flora of 20 000 species). Therefore the relationship between a host and a mistletoe can be a two way interaction, and the combination between hosts and mistletoes can be described as either a host-mistletoe combination (i.e. the host species for each mistletoe species, for example, *Amyema miquelii* has 125 host species, Downey 1998) or a mistletoe-host combination (i.e. the mistletoe species for each host species, for example, 17 mistletoes parasitise *Acacia aneura*, Downey 1996).

Theoretically, before a mistletoe species can be described as host-specific, a comprehensive list of its recorded host species must be collated from throughout its range. However, such lists, for any of the 88 aerial Australian mistletoe species, were unavailable prior to the host inventory of Downey (1998). The initial national host inventory was collated from records of the major Australian herbaria but was incomplete: five mistletoe species had no recorded host species, and some hosts were only documented to genus level. The incompleteness of the host inventory may be attributed to inadequate host collection.

Collection of hosts many be influenced by local conditions. For example, the type and number of plant species, and structure in a particular community can influence the number of host species available for colonisation (Hoffmann et al. 1986), and the dynamics of a community can influence the mistletoe species composition (Overton 1994, Dean et al. 1994, Downey et al. 1997). Furthermore, the number of potential host species present in any one location may not reflect the number of mistletoes species present. As an extreme example, Tasmania has numerous species that are recorded as mistletoe hosts on mainland Australia, but the island State has no mistletoe species present (Downey 1996). To evaluate the completeness of mistletoe host species lists, some scale (i.e. local or regional) of ground-truthing needs to be undertaken. This study examines host-mistletoe combinations in south-eastern New South Wales and compares them with the national host inventory compiled by Downey (1998).

Table 1. The mistletoe species present in the study area and information on their host species nationally (after Downey 1998).

Mistletoe species	Distribution in Australia	Distribution within study area	Number of specimens nationally	Number of host species nationally	Number of host families nationally
Loranthaceae					
Amyema cambagei (Blakely) Danser	Eastern Australia	widespread	258	10	5
Amyema congener (Sieber ex Schultes & J.H. Schultes) Tieghem	E & N Australia	coastal	340	90	31
Amyema miquelii (Lehm. ex Miq.) Tieghem	Australia wide	widespread	919	125	10
Amyema pendula (Sieber ex Sprengel) Tieghem	Eastern Australia	widespread	399	75	6
Dendrophthae vitellina (F. Muell.) Tieghem	Eastern Australia	coastal	346	76	29
Muellerina bidwillii (Benth.) Barlow	Eastern Australia	non-coastal	60	6	2
Muellerina eucalyptoides (DC.) Barlow	Eastern Australia	widespread	194	43	22
Viscaceae					
Notothixos carnifolius Oliver	Eastern Australia	non-coastal	105	8	4
Notothixos subaureus Oliver	Eastern Australia	coastal	237	35	10

Table 2. Number and percentage of new hosts for three mistletoe species recorded from south eastern NSW

Mistletoe species	Number of new host species	Number of host species (Downey 1998)	Total number of host species	Percentage increase from SE NSW
Amyema miquelii	1	125	126	1
Amyema pendula	8	75	83	10
Muellerina eucalyptoides	3	43	46	7

Methods

A network of transects was established in south-eastern New South Wales (including the Australian Capital Territory) based upon the major roads between Wee Jasper and Batemans Bay, via Canberra. The straight-line distance between Canberra and Batemans Bay is approximately 100 km. A transect extending both north and south of Batemans Bay, was added to include coastal vegetation. The study area included sub-alpine, temperate and coastal vegetation communities.

Nine mistletoe species from two families are known from this area (Table 1), six from the Australian Capital Territory and surrounding region (Burbidge & Gray 1970) and another three between the Great Dividing Range and Batemans Bay (Quirico 1992a, b). Host species for each of these mistletoe species are in the national inventory (Downey 1998).

Each of the main and secondary roads within the study area was traversed, forming separate 'transects'. Smaller confined areas were also sampled in and around Canberra (e.g. Cooleman Ridge and Mulligans Flat Nature Reserve). Each time a mistletoe plant was observed, the host-mistletoe combination was determined. If the combination was unknown, or if the host species could not be identified in the field, a herbarium specimen was collected for both the mistletoe and the host species. Each individual collection was numbered with an 'a' for the mistletoe species and a 'b' for the host species after the collection number (e.g. POD 106a & POD 106b). The location of each host-mistletoe combination was mapped using GIS software. All specimens are now located in the Australia National Herbarium (CANB). Some observed occurrences could not be collected because the mistletoe species and/or the host species were too high to collect suitable material for identification. Combinations were checked against the national host inventory (Downey 1998) to determine if the mistletoe-host combination had been previously recorded in Australia.

Mistletoe taxonomy followed Barlow (1984a, b) and host taxonomy followed Wilson and Johnson (1989), Harden (1991) and Tame (1992). M.I.H. Brooker (CANB) identified all Eucalypt hosts, including species assigned to *Eucalyptus* and *Corymbia*.

Results

All nine mistletoe species known to occur in the study area were collected (Table 1) as well as 31 different host species, forming 38 different host-mistletoe combinations (Appendix 1). Twenty-six of these host-mistletoe collections were previously recorded in the national host inventory (Downey 1998).

Three mistletoe species had new host species (Table 2). The number of previously known host species for a mistletoe species in 1998 was not a predictor of the number of new host species that were observed for the same mistletoe species in the present study (Table 1, 2). New host species were only observed for mistletoe species that had more than 40 documented host species and more than 190 collections nationally (Table 1, 2). For example, a new host was collected for *Amyema miquelii*, the Australian mistletoe species with the greatest number of known host species

Table 3. New host-mistletoe combinations collected in south-eastern NSW.

Mistletoe species	Host family	Host species	Host status[1]	Native host species outside of their natural range	Previous number of host combinations[2]
Amyema miquelii	Myrtaceae	*Eucalyptus crenulata*	New	yes	0
Amyema pendula	Mimosaceae	*Acacia floribunda*		yes	2
	Fabaceae	*Chamaecytisus palmensis**		yes	7
	Myrtaceae	*Eucalyptus elata*	New	no	0
	Myrtaceae	*Eucalyptus globoidea*		no	1
	Myrtaceae	*Eucalyptus nicholii*	New	yes	0
	Myrtaceae	*Eucalyptus pauciflora*		no	1
	Myrtaceae	*Eucalyptus rubida*		no	1
	Fagaceae	*Quercus palustris**	New	yes	0
Muellerina eucalyptoides	Myrtaceae	*Eucalyptus dalrympleana*		no	2
	Myrtaceae	*Eucalyptus globoidea*		no	1
	Myrtaceae	*Eucalyptus radiata*		no	1

[1] As recorded by Downey (1998)
[2] The number of combinations each host species is known from i.e. in Downey (1998)
* denotes exotic or introduced species to Australia

Table 4. Host-mistletoe combinations collected from the study area with five or fewer records nationally (Downey unpub. data), and the total number of records for each host species.

Mistletoe species	Host species	No. of times the combination had been previously recorded	No. of time the host has been previously recorded in a combination
Amyema congener	*Acacia mearnsii*	2	59
Amyema miquelii	*Eucalyptus bicostata*	2	2
	Eucalyptus polyanthemos	2	23
Amyema pendula	*Eucalyptus cinerea*	2	3
	Eucalyptus mannifera	3	6
	Eucalyptus ovata	5	6
	Eucalyptus radiata	5	5
Muellerina eucalyptoides	*Acacia floribunda*	1	2
	Eucalyptus cypellocarpa	1	1
	Eucalyptus pauciflora	2	2
	Eucalyptus sideroxylon	4	17

(Table 2). *Amyema pendula* had the highest number of new host species and the greatest percentage change in the total number of known host species from the national inventory (Table 2).

A total of 12 new host-mistletoe combinations were collected (Table 3). Eight combinations comprised a host species that was already known as a mistletoe host (Downey 1998), but not for the mistletoe species collected here. One of these new combination (*Amyema pendula* on *Eucalyptus pauciflora*) was collected from two separate locations; another (*Amyema pendula* on *Quercus palustris**) from three. Seven of the eight combinations contained host species that were previously only known as host species for either one or two other mistletoe species (Table 3). The other four new combinations included a host species which was not previously known as a host species (i.e. not recorded by Downey 1998) *viz. Eucalyptus crenulata, Eucalyptus elata, Eucalyptus nicholii*, and the exotic *Quercus palustris** (Table 3). Locations of new combinations or new host species were dispersed throughout the study area (Fig. 1).

A further 11 combinations were poorly-documented i.e. known from less than six collections nationally (Table 4). Two of these combinations had only been collected once before.

Five of the new combinations had host species which were considered to be either non-indigenous (three hosts), in that they were Australian natives outside of their natural range, or introduced or exotic to Australia (two hosts: Table 3); one of these was a new host (*Amyema pendula* on the exotic *Quercus palustris**).

There were no additional host families observed, however, one mistletoe species, *Amyema pendula*, increased the number of host families it parasitised by two (Fagaceae and Fabaceae). *Eucalyptus* and *Acacia* species comprised the majority of host species.

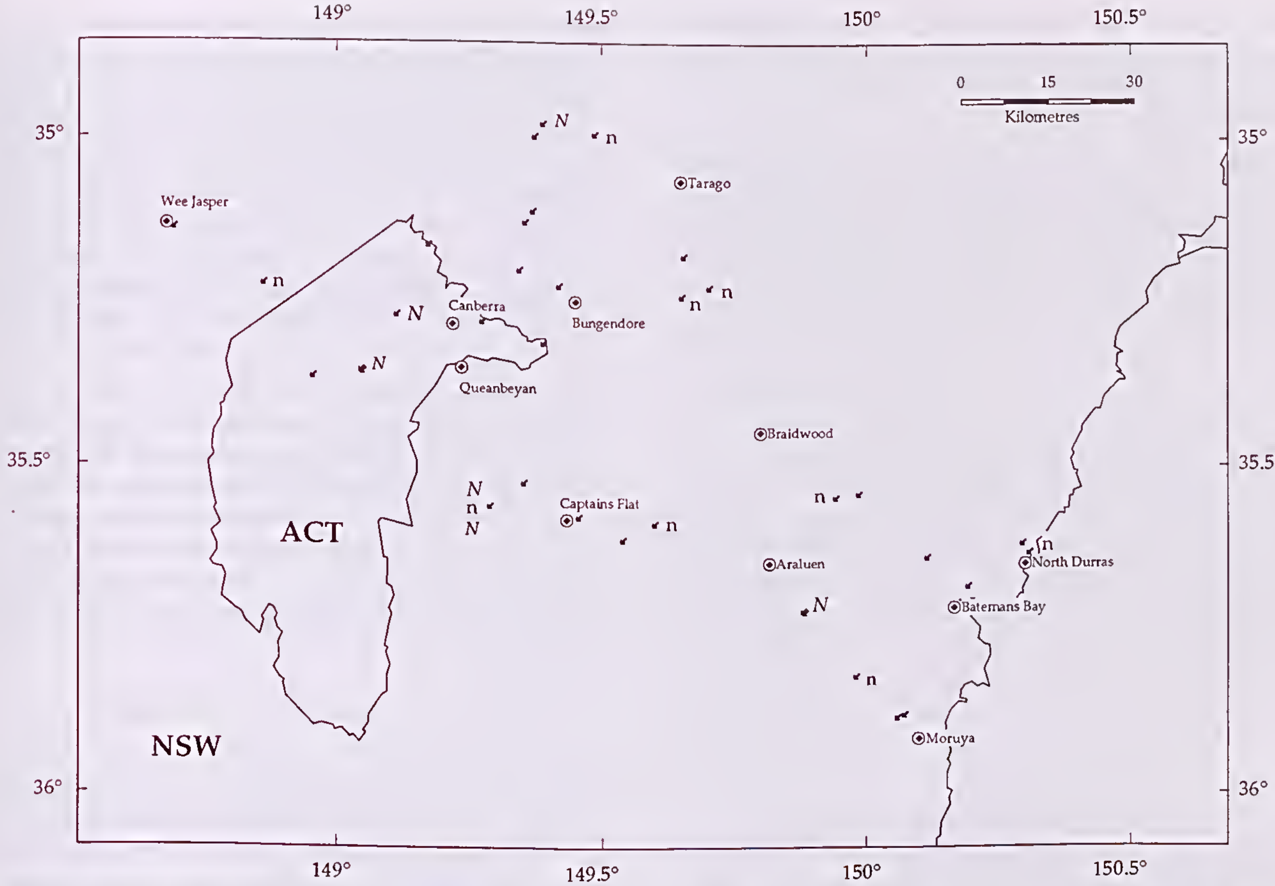

Fig. 1. The location of mistletoe and host collections (↙) made within the study area and the location of new host species (*N*) and host-mistletoe combinations (n).

Discussion

The present study showed that host-mistletoe combinations in southern New South Wales (including Australian Capital Territory) have not been thoroughly examined and suggests that the national host inventory (Downey 1998) is incomplete. The are several reasons why the host inventory may be incomplete: (i) mistletoe hosts are not always collected or identified correctly, which may bias information on host dynamics, (ii) dedicated investigation of host species have not occurred, (iii) in the absence of a host inventory new hosts maybe overlooked, or (iv) host-mistletoe combinations are dynamic in a number of ways.

(i) Collection of host species

Compilations of mistletoe host species from herbaria records may not encapsulate the complete set of host species, as illustrated by five mistletoe species that had no host records in the 1998 inventory (see Downey 1998). One of the problems with this host inventory is that it was derived from mistletoe collections, not host collections, and is incomplete, as hosts are not always documented. In addition, collectors do not typically collect or note the other host species that are present in the area, or collect the same mistletoe species close by on a separate host species (Barlow pers. comm.).

Host species are not collected for a number of reasons: (i) insufficient material to make an identification at the time of collection, (ii) collecting techniques employed, (iii) collector's knowledge of the host species, or (iv) height of the host. For example, the specimen of *Muellerina eucalyptoides* collected here from *Eucalyptus cypellocarpa* was approximately seven metres from the ground and the host tree was approximately 45 metres tall, with few branches below 20 metres; making a the collection of a herbarium specimen difficult. Similarly, no mistletoe collections have been made from *Eucalyptus regnans*, despite several reports of mistletoes growing on it (Patton 1917, Coleman 1949, A.M. Gill pers. comm.). Highlighting the difficulty of collecting from very tall trees, there are only 16 collections of *E. regnans* in the Australian National Herbarium (CANB).

(ii) Targeted mistletoe host surveys

Targeted mistletoe host surveys are rare, especially over a large area, like southern New South Wales. The only other published targeted survey was undertaken by Moss (1998) from south-east Queensland. Comparisons of Moss' (1998) host lists with the national host inventory revealed 50 new mistletoe-host combinations, from 90 combinations observed for 16 mistletoe species. Of these new combinations 23 contained new host species (i.e. not recorded in the national inventory). Apart from Moss (1998), host lists tend to be the result of generic surveys over a confined area. While such lists can add valuable information on host species, they may not reflect geographic variation in host species or the mistletoe species.

Downey (1996) found that the greater the number of mistletoe collections, the greater the number of host species; therefore targeted surveys could reveal new hosts, especially in poorly collected areas. The present targeted survey in part supports this finding in that new host species were only recorded for mistletoe species with many recorded collections and hosts. The widespread nature of these mistletoe species, with high collections and host numbers, may influence their ability to have many host species, as their distribution overlaps the distributions of many hosts (Downey 1996), and they are more likely to be collected. Targeted surveys which involve mistletoes that are poorly collected (or known) are likely to reveal new host-mistletoe combinations. For example, a localised survey of *Muellerina myrtifolia* from southern Queensland revealed three new mistletoe-host combinations and two new host species from six collections. The national inventory contained four host-mistletoe combinations (to species level and one to genus) from 24 collections of *Muellerina myrtifolia* (Downey unpub. data, Downey & Halasz in prep.).

On a local scale, there is a limited number of potential host species available for colonization at any one site. Nearby sites may contain different host species or different densities of host plants which may affect the suite of mistletoe species present at that location (Overton 1994). It is important to consider populations of mistletoe populations or mistletoe meta-populations when investigating their host species. The suggestion that host specificity at species rank occurs mainly on a local scale, has been put forward by Norton et al. (1995). This phenomenon may be based on the number of potential hosts available at a particular location, or it may be that a mistletoe species may only parasitise a portion of its total host set at a given location (Overton 1994). Either case may mislead observers into thinking that host specificity occurs over the entire distribution of the mistletoe, or on a national scale.

All nine mistletoe species collected within the study area had patchy or disjunct distributions on a local scale, supporting observations by others (e.g. May 1941, Norton et al. 1995). The spatial distribution of the new combinations (see Fig. 1) was dispersed throughout the study area.

Trees in roadside corridors in Western Australia contained very low densities of mistletoes compared with larger woodland fragments (Norton et al. 1995); elsewhere roadsides increase mistletoe density (Norton & Stafford Smith 1999). Roadside surveys like the current study could influence the number of hosts observed. Distribution data from 9000 Australian mistletoe specimens revealed a road map of Australia (Downey 1996), suggesting that the majority of herbarium collections are made along roads. Targeted host surveys need to account for variations in the landscape and not just sample roadsides.

(iii) Absence of a host inventory

In the absence of a host inventory some host species may be overlooked, as there is no way to determine if a host species is a new record. Some host species may be observed and noted on a regional basis (e.g. Moss 1998) but not collated anywhere. Such regional records were not included when the national host inventory was compiled but have been included in the revised inventory (Downey & Halasz in prep.). Herbarium vouchering of such observations may not occur or take a long time to occur, for example, Blakely (1922) noted *Amyema pendula* growing on *Chamaecytisus palmensis**, but it was not until the current study, some eighty years later, that this mistletoe-host combination was collected. The absence of a host inventory prevents analysis of the nature of mistletoe-host combinations. For example, *Quercus palustris** was not recorded in the host inventory, but was noted as a host for *Muellerina eucalyptoides* (Seebeck 1997) and *Amyema pendula* (here). The presence of a host inventory stimulates collection of hosts, and discussion and better understanding of host species.

(iv) The dynamics of host-mistletoe combinations

Host-mistletoe combinations may be dynamic. Evidence presented here suggests that mistletoe species have the ability to expand their suite of host species. Such expansions may occur either fortuitously through the introduction of exotic and/or native host species that are not indigenous to that area or as result of evolutionary pressures (Norton & Carpenter 1998, Norton & de Lange 1999) which might arise in response to environmental pressures like habitat modification (Norton & Stafford Smith 1999) and climate change (e.g. based on *Viscum album* in Europe, Jeffree & Jeffree 1996). The exact way in which host expansion occurs is not clear, but may result from these processes independently or from other factors like avian dispersers (Liddy 1983, Buen & Ornelas 1999, Lavorel et al. 1999), temporal component of relative host abundance (Norton & de Lange 1999), or any combination of these. Irrespective of these factors host expansion can be limited by the plants that mistletoes are dispersed to, as some plants can prevent mistletoe parasitism. For example, some host species have their own mechanisms for resistance to haustorial penetration and development. These mechanism include: bark resistance (Hoffmann et al. 1986, Hariri et al. 1987, Yan 1993); bark thickness (Littlejohns 1950); bark texture (Morgan 1914); branch diameter (Reid 1991); branch age (Liddy 1983); xylem resistance (Hoffmann et al. 1986, Yan 1993) and; previous infestation of the host (Hoffmann et al. 1986). Thus, host resistance may explain why some plants are free from infection (Hoffmann et al. 1986) and explain limitations to host expansion.

The floristic dynamics of the mistletoe-host combinations observed were not explored here, in part due to the small sample size. Examination of the major host genera (*Eucalyptus* and *Acacia*) and their mistletoe species at a national level has been inconclusive i.e. at the sub-generic level of *Eucalyptus* (Downey 1996), and at the time of writing, analysis of the updated host inventory (Downey and Halasz in prep.) is not available. New hosts identified since the host inventory (Downey 1998) show a wide floristic diversity (Downey unpublished data, Downey and Halasz in prep.), and examination of mistletoe distribution patterns show that mistletoe diversity is lowest where host diversity is low i.e. in arid Australia (see Downey & Gill in prep.). An analysis of the phytogeography of host-mistletoe combinations could not be undertaken due to the limited distribution data for many host species (see Downey & Gill in prep.).

The introduction of exotic species and expansion of native species to new ranges can lead to potential new (or 'novel') host species. Many exotic species have been recorded as mistletoe hosts (Johncock 1903, Blakely 1922, Hart 1961, Marshall 1981, Seebeck 1997, de Lange et al. 1997, Downey 1998, Downey & Halasz in prep.). The current study recorded several native host species outside of their natural range, highlighting the dynamic mistletoe-host interactions associated with 'novel' host species. The number of new combinations observed, increased where there was an increase in the number of native plant species outside of their natural range (e.g. private acreage near reserves in Canberra), suggesting that garden plants provide a substantial source of new hosts. The colonization of new hosts or host-switching may ultimately lead to mistletoe speciation (Norton & Carpenter 1998).

The number of introduced species globally has increased dramatically over the past 200 years (di Castri 1989, Reichard & Hamilton 1997) and the number of exotic hosts will increase in the future (Humphries et al. 1991). The number of mistletoe species which parasitise introduced species is likely to increase as these introduced species increase their distribution. For example, Seebeck (1997) noted *Muellerina eucalyptoides* growing on *Quercus palustris**, which was collected subsequently in this study as a host of *Amyema pendula*. Regular updates of the host inventory will allow the capture of these dynamic interactions. Similarly, there are several exotic species in Australia which are not known to be mistletoe hosts, but are known to host mistletoes elsewhere in their exotic range (e.g. *Cytisus scoparius* in New Zealand: de Lange et al. 1997, Downey & Halasz in prep.). The role introduced hosts play in mistletoe colonization needs further study. As mistletoe abundance varies between hosts (see Norton & Carpenter 1998, Buen & Ornelas 1999) the density of mistletoes on 'novel' and 'normal' hosts should be included in any such studies.

The ability of mistletoe species to parasitise species that they have never previously encountered makes the prediction of possible host species difficult, questions host-specificity and poses interesting management dilemmas. For example, the ability of endangered New Zealand mistletoes to grow on exotic species (de Lange et al. 1997, Downey & Halasz in prep.) may help their management (Reid 1998).

Conclusion

The national host inventory is incomplete at least in south-eastern New South Wales. There are several possible reasons for this incompleteness. Host-mistletoe combinations are dynamic and new host combinations with known mistletoe hosts are continuing to be documented. The reasons for the dynamic nature of host-mistletoe combinations include the presence of 'novel' (i.e. exotic or 'non'-indigenous) host species. Targeted surveys like this one are extremely important to our understanding of host-mistletoe relationships.

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References

Atsatt, P.R. (1983) Host-parasite interactions in higher plants. In O.L. Lange, P.S. Nobel, C.B. Osmond & H. Ziegler (eds.) *Physiological Plant Ecology III: Responses to the chemical & biological environment*. Encyclopedia of plant physiology, New series, Vol 12C. pp. 519–535 (Springer-Verlag: Berlin).

Barlow, B.A. (1981) The Australian flora: its origin & evolution. In A.S. George (Ed.) *Flora of Australia: Introduction*. Vol 1. pp. 25–75 (Bureau of Flora and Fauna, Australian Government Publishing Service: Canberra).

Barlow, B.A. (1984a) Loranthaceae. In A.S. George (Ed.) *Flora of Australia: Rhizophorales to Celastrales*. Vol 22. pp. 68–131 (Bureau of Flora and Fauna, Australian Government Publishing Service: Canberra).

Barlow, B.A. (1984b) Viscaceae. In A.S. George (Ed.) *Flora of Australia: Rhizophorales to Celastrales*. Vol 22. Pp. 131–145 (Bureau of Flora and Fauna, Australian Government Publishing Service: Canberra).

Barlow, B.A. & Wiens, D. (1977) Host-parasite resemblance in Australian mistletoes: the case for cryptic mimicry. *Evolution* 31: 69–84.

Blakely, W.F. (1922) The Loranthaceae of Australia. Part 1. *Proceedings of the Linnean Society of New South Wales* 47: 1–25.

Buen, L.L. & Ornelas, J.F. (1999) Frugivorous birds, host selection & mistletoe *Psittacanthus schiedeanus*, in central Veracruz, Mexico. *Journal of Tropical Ecology* 15: 329–340.

Burbidge, N.T. & Gray, M. (1970) *Flora of the Australian Capital Territory*. (Australian National University Press: Canberra).

Coleman, E. (1949) Menace of the mistletoe. *The Victorian Naturalist* 66: 24–33.

Dean, W.R.J., Midgley, J.J. & Stock, W.D. (1994) The distribution of mistletoes in South Africa: patterns of species richness & host choice. *Journal of Biogeography* 21: 503–510.

de Lange, P.J., Norton, D.A. & Molloy, B.J.P. (1997) An annotated checklist of New Zealand Mistletoe (Loranthaceae) hosts. In P.J. de Lange & D.A. Norton (Eds) *New Zealand's Loranthaceous mistletoes*. pp. 83–105 (Department of Conservation: Wellington).

di Castri, F. (1989) History of biological invasions with emphasis on the Old World. In J. Drake, F. di Castri, R.H. Groves, F. Kruger, H.A. Mooney, M. Rejmánek & M. Williamson (Eds) *Biological Invasions: A global perspective*. pp. 1–30 (John Wiley: New York).

Downey, P.O. (1996) *Host-mistletoe Combinations in Australia*. Honours Thesis (Australian National University: Canberra).

Downey, P.O. (1998) An inventory of host species of each aerial mistletoe species (Loranthaceae & Viscaceae) in Australia. *Cunninghamia* 5(3): 685–720.

Downey, P.O. & Gill, A.M. (in prep.) Phytogeography of aerial mistletoes (Loranthaceae and Viscaceae) in Australia.

Downey, P.O. & Halasz, L. (in prep.) A revised inventory of host species of each aerial mistletoe species (Loranthaceae and Viscaceae) in Australia and New Zealand.

Downey, P.O., Gill, A.M. & Banks, J.C.G. (1997) The influence of host attributes on mistletoe colonization: an example from Mulligan's Flat Nature Reserve, A.C.T. *The Victorian Naturalist* 114: 110–115.

Hariri, E.B., Andary, C. & Salle G. (1987) New insights on the resistance against mistletoe (*Viscum album* L.). In H.Chr. Weber & W. Forstreuter (eds) *Parasitic Flowering Plants*. pp. 293–294 (Marburg, F.R.G.).

Harden, G.J. (ed.) (1991) *Flora of New South Wales: Vol 2*. (New South Wales University Press: Sydney).

Hart, T.S. (1961) Do mistletoes kill their hosts? *The Victorian Naturalist* 57: 215.

Hoffmann, A.J., Fuentes, E.R., Cortés, I., Liberona, F. & Costa, V. (1986) *Tristerix tetrandrus* (Loranthaceae) and its host-plants in the Chilean matorral: patterns & mechanisms. *Oecologia* 69: 202–206.

Humphries, S.E., Groves, R.H. & Mitchell, D.S. (1991) Plant invasions of Australian ecosystems: A status review and management directions. *Kowari* 2: 1–134.

Jeffree, C.E. & Jeffree, E.P. (1996) Redistribution of the potential geographical ranges of mistletoe and Colorado beetle in Europe in response to temperature component of climate change. *Functional Ecology* 10(5): 562–577.

Johncock, C.F. (1903) Notes on *Loranthus exocarpi*. *Transactions of the Royal Society of South Australia* 27: 253–255.

Kuijt, J. (1969) *The Biology of Parasitic Flowering Plants*. (University of California Press: Berkeley).

Lavorel, S., Stafford Smith, M. & Reid, N. (1999) Spread of mistletoe (*Amyema preissii*) in fragmented Australian woodlands: a simulation study. *Landscape Ecology* 14: 147–160.

Liddy, J. (1983) Dispersal of Australian mistletoes: the Cowiebank study. In D.M. Calder & P. Bernhardt (eds) *The biology of mistletoes*. pp 101–116 (Academic Press: Sydney).

Littlejohns, R.T. (1950) Further notes on the mistletoe bird and mistletoe parasite. *Emu* 50: 84-90.

Marshall, K.J. (1981) Mistletoe in introduced trees. *The Victorian Naturalist* 89: 233.

May, V. (1941) A survey of the mistletoe of New South Wales. *Proceedings of the Linnean Society of New South Wales* 66: 77–87.

Morgan, A.M. (1914) A note on *Dicaeum hirundinaceam* and the *Loranthus* seed. *S.A.Orn.* 1: 21–22.

Moss, J.T.St.L. (1998) Mistletoe/hostplant associations of the Barakula, Columboola and Gurulmundi region, south-east Queensland. *Queensland Naturalist* 36(4–6): 73–87.

Norton, D.A. & Carpenter, M.A. (1998) Mistletoes as parasites: host specificity and speciation. *Trends in Ecology and Evolution* 13(3): 101–105.

Norton, D.A. & de Lange, P.J. (1999) Host specificity in parasitic mistletoes (Loranthaceae) in New Zealand. *Functional Ecology* 13: 552–559.

Norton, D.A. & Stafford Smith, M. (1999) Why might roadside mulgas be better mistletoe hosts? *Australian Journal of Ecology* 24: 193–198.

Norton, D.A., Hobbs, R.J. & Atkins, L. (1995) Fragmentation, disturbance, and plant distribution: mistletoes in woodland remnants in the Western Australian wheatbelt. *Conservation Biology* 9: 426–438.

Overton, J.M. (1994) Dispersal and infection in mistletoe metapopulations. *Journal of Ecology* 82: 711–723.

Patton, R.T. (1917) Timber production and growth curves in the Mountain Ash (*Eucalyptus regnans*). *Proceeding of the Royal Society of Victoria* 30: 1–3.

Quirico, A.L. (1992a) Loranthaceae. In G.J. Harden (Ed.) *Flora of New South Wales*. Vol. 3. pp. 46–55 (New South Wales University Press: Sydney).

Quirico, A.L. (1992b) Viscaceae. In G.J. Harden (Ed.) *Flora of New South Wales*. Vol. 3. pp. 61–65 (New South Wales University Press: Sydney).

Reichard, S.H. & Hamilton, C.W. (1997) Predicting invasions of woody plants introduced into North America. *Conservation Biology* 11: 193–203.

Reid, N. (1991) Coevolution of mistletoes and frugivorous birds? *Australian Journal of Ecology* 16: 457–469.

Reid, N., Stafford Smith, M. & Yan, Z. (1995) Ecology and population biology of mistletoes. In M.D. Lowman & N.M. Nadkarni (Eds) *Forest Canopies*. pp. 285–310 (Academic Press: San Diego).

Reid, V.A. (1988) *The Impact of Weeds on Threatened Plants*. Science and research internal report no. 164 (Department of Conservation: Wellington).

Seebeck, J. (1997) Creeping mistletoe *Muellerina eucalyptoides* in suburban Melbourne. *The Victorian Naturalist* 114: 130–134.

Tame, T. (1992) *Acacias of southeast Australia*. (Kangaroo Press: Kenthurst).

Wilson, K.L. & Johnson, L.A.S. (1989) Casuarinaceae. In A.S. George (Ed.) *Flora of Australia: Hamamelidales to Casuarinales*. Vol. 3. pp. 100–174 (Bureau of Flora and Fauna, Australian Government Publishing Service: Canberra).

Yan, Z. (1990) *Factors affecting host specificity of two mistletoes* Amyema preissii *and* Lysiana exocarpi. PhD Dissertation (Flinders University: Adelaide).

Yan, Z. (1993) Resistance to haustorial development of two mistletoes, *Amyema preissii* (Miq.) Tieghem & *Lysiana exocarpi* (Behr.) Tieghem ssp. *exocarpi* (Loranthaceae), on host and nonhost species. *International Journal of Plant Sciences* 154: 386–394.

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Appendix 1. Host-mistletoe combinations collected in the study

Mistletoe family	**Mistletoe species**	**Host family**	**Host species**
Loranthaceae	*Amyema cambagei*	Casuarinaceae	*Casuarina cunninghamiana*
	Amyema congener	Mimosaceae	*Acacia mearnsii*
	Amyema miquelii	Myrtaceae	*Eucalyptus bicostata*
		Myrtaceae	*Eucalyptus blakelyi*
		Myrtaceae	*Eucalyptus crenulata*
		Myrtaceae	*Eucalyptus polyanthemos*
		Myrtaceae	*Eucalyptus sideroxylon*
	Amyema pendula	Mimosaceae	*Acacia dealbata*
		Mimosaceae	*Acacia floribunda*
		Mimosaceae	*Acacia mearnsii*
		Mimosaceae	*Acacia melanoxylon*
		Fabaceae	*Chamaecytisus palmensis**
		Myrtaceae	*Eucalyptus bridgesiana*
		Myrtaceae	*Eucalyptus cinerea*
		Myrtaceae	*Eucalyptus elata*
		Myrtaceae	*Eucalyptus globoidea*
		Myrtaceae	*Eucalyptus macrorrhyncha*
		Myrtaceae	*Eucalyptus mannifera*
		Myrtaceae	*Eucalyptus nicholii*
		Myrtaceae	*Eucalyptus ovata*
		Myrtaceae	*Eucalyptus pauciflora*
		Myrtaceae	*Eucalyptus radiata*
		Myrtaceae	*Eucalyptus rubida*
		Myrtaceae	*Eucalyptus viminalis*
		Fagaceae	*Quercus palustris**
	Dendrophthoe vitellina	Myrtaceae	*Eucalyptus maculata*
	Muellerina bidwillii	Cupressaceae	*Callitris endlicheri*
	Muellerina eucalyptoides	Mimosaceae	*Acacia floribunda*
		Myrtaceae	*Angophora costata*
		Myrtaceae	*Eucalyptus blakelyi*
		Myrtaceae	*Eucalyptus cypellocarpa*
		Myrtaceae	*Eucalyptus dalrympleana*
		Myrtaceae	*Eucalyptus globoidea*
		Myrtaceae	*Eucalyptus pauciflora*
		Myrtaceae	*Eucalyptus radiata*
		Myrtaceae	*Eucalyptus sideroxylon*
Viscaceae	*Notothixos cornifolius*	Sterculiaceae	*Brachychiton populneus*
	Notothixos subaureus	Loranthaceae	*Muellerina eucalyptoides*

* denotes exotic or introduced species to Australia

Floristic patterns in coastal rainforest of Shoalwater Bay, Central Queensland

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Abstract: A study was undertaken of the floristic patterns in coastal rainforest (low closed forest) of Shoalwater Bay, central Queensland. The site encompasses 60 km of coastline, extending from latitude 22° 08' 30" to 22° 30' 0" and longitude 150° 02' 00" to 150° 24' 30". The rainforest grows on coastal Holocene sand dunes, swales and sand flats, distributed as a series of 27 discrete patches greater than one hectare along 60 kilometres of coastline. Mean patch size was 10.7 hectares (maximum 150 hectares). The flora was predominantly woody, and lacked the complex growth forms of Webb (1968). Floristic links with central and north Queensland were strong, with some species distributions extending into Malesia and the Pacific. Three physical strata, emergent (composed of trees), canopy (composed of trees, vines and epiphytes) and sub-canopy (trees, vines and herbs) were recognised. The herb layer was very poorly developed. Eighty-one species were recorded, representing 42 families and 72 genera.

Sixty three quadrats were sampled across the rainforest patches to measure abundance of all vascular taxa using frequency score. Five floristic groups were defined from agglomerative classification analysis, one representing mixed forest, two representing low microphyll vine forest (LMVF) and two representing microphyll vine thicket (MVT). The vegetation at the study site was predominantly MVT. Five species groups were defined, one correlated with the mixed forest, one with the LMVF and one with the MVT. The remaining species groups represented ubiquitous and widespread species. Floristic patterns were found to be strongly influenced by three environmental variables using canonical correspondence analysis. The strongest variable was drainage, which separated the mixed forest from the vine forest/thicket. The LMVF/MVT vegetation forms a continuum along an environmental gradient, influenced by exposure to onshore-winds and landform height. The mesic/protected extreme was represented by the tallest LMVF situated in swales, whilst at the exposure/elevation extreme was represented by wind-sheared MVT located on foredunes.

***Cunninghamia* (2004) 8(3): 362–370**

Introduction

Rainforest established on coastal sands are located along the tropical and sub-tropical coast of Australia, extending as a discontinuous belt from north-western Western Australia to southern New South Wales (Adam 1992). In common with rainforest established on other substrates, the physical and floristic characters of coastal rainforest on sand may vary considerably from 'core' rainforest areas, due to climatic variations of the Australian littoral zone. Rainforest ecology studies have found that these communities experience extreme environmental variables (Baur 1962; Floyd 1990a; Tracey 1982).

Along the Queensland coast, these rainforest communities are often described as beach scrubs (Batianoff and McDonald 1980; Young and McDonald 1987). They are often floristically depauperate, and much reduced in stature. Their ecology is poorly known when compared with the more aesthetically pleasing rainforests in high rainfall areas (Gillison 1987).

The presence of coastal rainforest on sands of Holocene origin has been widely noted (Russell-Smith & Dunlop 1987, Byrnes et al. 1977, Batianoff & McDonald 1980, Floyd 1990a, Hopkins et al. 1979). The flora is composed of species that are widely distributed and highly vagile, having successfully colonised these Holocene landforms (Russell-Smith & Dunlop 1987). The topographical protection from fire is an important aspect of coastal rainforest persistence, as coastal rainforest communities are generally destroyed by fire. The expansion of rainforest communities in the absence of fire has been noted by several authors (Dunlop et al. 1975, Dunlop 1976, Tracey 1982, Bowman 1990).

The effects of wind sheer from exposure to on-shore winds and periodic storms of a highly destructive nature contribute to the low, wind-sheared forms of coastal rainforest, exacerbated by frontal dune topology. Open forest structures are attributed to meteorological disturbances (Tracey 1982, Floyd 1990a). Soil water status and the access to aquifers and water tables appears to favour the development of coastal rainforest in many locations. Where seasonal access to subsurface moisture occurs, the deciduous component predominates (Russell-Smith & Dunlop 1987, QDEH 1994, Specht et al. 1977). Bowman (2000) however, questions the requirement of aquifers to support many types of dry rainforest. In coastal situations, impeded drainage favours the establishment of palm forests intermixed with rainforest. Where surface water persists for longer periods, replacement by *Melaleuca* communities is reported (Tracey 1982).

The *de novo* establishment of rainforest and the re-establishment of degraded coastal rainforest under current climatic conditions appears to be limited. More favourable climatic conditions are thought to have occurred during the Holocene, which has been attributed to the original establishment of coastal sands rainforest (Floyd 1990a). Where displacement has occurred, eucalypt woodlands and grasslands become established (Dunlop 1976, Tracey 1982).

The purpose of this study was to investigate the local scale floristic patterns of coastal rainforest along the poorly known Shoalwater Bay section of the Queensland coastline. The coastal rainforests of Shoalwater Bay are relatively undisturbed, unlike many coastal areas of Queensland where urban development has destroyed or modified significant areas. The study seeks to answer two basic questions: (1) are there local-scale patterns of species distribution and abundance? (2) Do these patterns relate to environmental variables?

Study area

The study area was located on the western shore of Shoalwater Bay, 180 km north of Rockhampton (Fig. 1). It encompasses 60 km of coastline from Parker Creek in the north (22° 08' 30") to Raspberry Creek in the south (22° 30' 0"). The Holocene sand deposits of the coastline are broadly classified as calcareous sands (BPA 1979), often with a capping of siliceous sands from aeolian deposition (Hopkins et al. 1979). Sand landforms along Shoalwater Bay are frontal dunes and parallel beach ridges. Parallel beach ridges have degraded into flat sand deposits, with one or two dunes or swales evident.

The Shoalwater Bay coastline was classified by Dick (1975) as warm and moist with a summer rainfall maximum. The key features of the study area's rainfall are the distinct seasonality and the high variability on a year-to-year basis. The average rainfall is 894 mm, with 63% recorded in the months December to March, calculated from a discontinuous series of recordings at Couti Outi (1964–1975), Stanage Bay (1915–1919), Langham (1986–1998) and Hollins Bay (1972–1974). The mean annual maximum temperature for the nearest recording station of St. Lawrence is 28.3°C, and the mean annual minimum is 17.2°C.

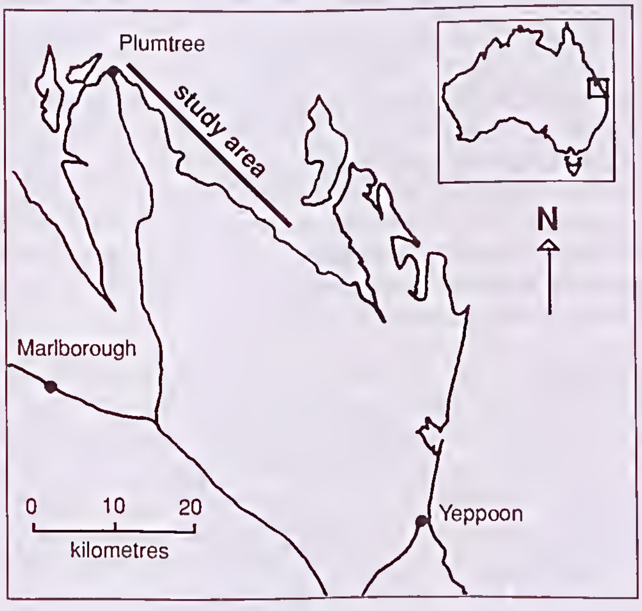

Fig. 1. Location of study site on the western shore of Shoalwater

The central Queensland coast is frost free and the temperature range is conducive to growth 12 months of the year. However, summer heat waves and high evaporation, particularly in the winter and spring period can limit plant growth (BPA 1979). Wind strength is consistently moderate to fresh with velocities exceeding 20 kph for about 30% of the time, with almost no calm days (BPA 1979). Cyclones pass within 150 km of the St. Lawrence recording station on average every 2.6 years. Associated with these disturbances are wind speeds up to 160 kph, and storm tides of up to 1.2 m (ABARE et al. 1993, BPA 1979, BPA 1982).

Materials and methods

The study area rainforest was mapped at a 1:10 000 scale by aerial photograph interpretation. The aerial photographs were a colour series taken by the Department of Defence on September 1975 at a scale of 1:30 000, and a 1987 black and white series at a scale of 1:26 000 from Sunmap. Ground traverses were carried out along the entire length of the coastline to confirm the aerial interpretations.

A floristic survey was carried out using a frequency score method (Outhred 1984, Morrison et al. 1995). This method employed seven sub-quadrats of size 5, 10, 20, 40, 80, 160 and 320 m^2. Species presence/absence was recorded for each sub-quadrat, producing an abundance score from 0 to 7. Seven combinations of morphology, drainage and vegetation type were sampled, replicated three times, giving 21 patches. Triplicate quadrats we randomly located in the selected patch. A total of 63 quadrats were sampled. All species occurring in less than three quadrats were discarded from multivariate analysis. Plant identifications were verified where necessary by checking specimens at the Queensland Herbarium, and nomenclature follows Forster et al. (1991), updated with reference to Harden (1990–93) where possible.

All data were stored using Microsoft Excel (Microsoft 1994) on a personal computer. Numerical classification was carried out using PATN (Belbin 1993). An association matrix for classification of quadrats was generated using the symmetric form of the Kulczynski co-efficient (PATN module ASO). Agglomerative hierarchical fusion was carried out using flexible UPGMA, with beta –0.1 (PATN module FUSE). Dendrograms were produced from the fusion results (PATN module DEND). For ordination analysis, CANOCO was employed (ter Braak 1988). The canonical correspondence analysis option in CANOCO was chosen, with the underlying assumption that species distribution are unimodal. Environmental factors were recorded for each quadrat. Variables were distance from high water mark (h.w.m); continuous, elevation above h.w.m; continuous, latitude; continuous, vegetation type; binary, landform; 3 states, exposure; 4 states and drainage; binary.

Results

The coastal rainforest of Shoalwater Bay was distributed as a series of 27 discrete patches greater than one hectare extent, along the 60 km of coastline surveyed. The patch mean patch size was 10.7 ha, with the largest patch encompassing 150 ha.

Three geomorphological formations supporting rainforest were distinguished: 1. foredunes, with a windward and leeward aspect, encompassed 9.2% and 10.7% respectively of the rainforest area, 2. flat sand masses, with free draining and poorly draining forms, accounted for 70.4% and 7.0% respectively of the area, and 3. swales, which accounted for 2.8% of the area.

Three rainforest vegetation types were distinguished in the aerial photographs and ground traverses. Rainforest was present as; 1. patchy rainforest without sclerophyll emergents interspersed with areas of bare sand, 2. dense rainforest without sclerophyll emergents or 3. rainforest with sclerophyll emergents,. The occurrence of each rainforest vegetation type across the geomorphological formations is shown in Table 1, along with the quadrat codes employed in the classification analysis.

In total, 81 native vascular rainforest plant taxa were recorded at the study site, from 72 genera and 42 families (Appendix 1). The most common species were the canopy vine *Jasminum simplicifolium*, and the canopy trees *Exocarpos latifolius, Pouteria sericea*, *Drypetes deplanchei* and *Diospyros geminata*. The most common families were Rubiaceae, Rutaceae, Sapindaceae, Asclepiadaceae, Oleaceae and Apocynaceae.

The vegetation was predominantly woody, with three physical strata delineated. The emergent layer was composed of trees, the canopy layer was composed of trees, vines and epiphytes, and the sub-canopy layer was composed of trees and vines. The herb layer was poorly developed, with occasional occurrences of *Ancistrachne uncinulata* and *Cyperus eglobosus*.

The classification of quadrat data showed a strong spatial pattern of floristic composition within the study site (Fig. 2). At the two group level, the 9 quadrats placed in the rainforest vegetation with sclerophyll emergents are clearly separated from the remaining 54 quadrats (quadrat group 1). At the three group level, 15 quadrats located in swales and leeward aspect of frontal dunes, supporting dense rainforest vegetation without sclerophyll emergents, are separated from the 39 remaining quadrats. These 14 quadrats are further divided at the 5 group level into a group with all 9 swale quadrats of the study (quadrat group 2) and the 6 leeward frontal dunes sites (quadrat group 3).

The remaining 39 quadrats are separated at the five group level, forming 21 quadrats in quadrat group 4, consisting of leeward and windward foredune and flat geomorphologies, and supporting a mix of dense and patchy rainforest without sclerophyll emergents. Quadrat group 5 containing the remaining 18 quadrats supported patchy rainforest without sclerophyll emergents, located on leeward and windward foredune and flat geomorphologies.

Table 1. Areal extent of the three rainforest vegetation types classified by geomorphology and drainage. Quadrat code follows the percentage area for each combination: p-patchy or type 1, d-dense or type 2, s-sclerophyll emergents or type 3 vegetation; f-windward foredune, h-leeward foredune, s-swale, t-flat geomorphology; f-free draining, i-impeded drainage.

Geomorph.	**Drainage**	**Community (%)**			**Total (%)**
		(1)	**(2)**	**(3)**	
Windward foredune	free	9.2% (pff)	absent	absent	9.2%
Leeward foredune	free	4.4% (phf)	6.3% (dhf)	absent	10.7%
Swale	free	absent	2.8% (dsf)	absent	2.8%
Flat	free	9.0% (ptf)	61.4% (dtf)	absent	70.4%
Flat	impeded	absent	absent	7.0% (sti)	7.0%
Total		22.6%	70.4%	7.0%	100%

The two-way table analysis (Fig. 3) highlights three species group/quadrat group relationships. Species group 1, with 6 species, is associated with the quadrats of group 1. This species group contains the sclerophyll emergents *Corymbia tessellaris and Melaleuca leucadendra*, and the palm *Livistona decipiens.* Along with the herb *Cyperus eglobosus*, these four species were restricted to quadrat group one. They impart a distinctive physical structure to this quadrat group, with *Cyperus eglobosus* forming a prominent herb layer in several quadrats. Species group 2 contains 14 species, and is associated with quadrat group 2. *Terminalia porphyrocarpa* and *Turraea pubescens* are confined to this quadrat group, and along with *Bridelia leichhardtii* and *Olea paniculata* form a distinctive floristic component. Species group 3, with 12 species, is correlated with quadrat groups 4 and 5. *Notelea microcarpa, Pleurostylia opposita, Hoya australis, Cassytha pubescens, Amyema congener* and *Parsonsia plaesiophylla* are restricted to these quadrat groups. Vines are far more prominent in both the floristic and physical constitution of the vegetation of these quadrat groups. Species group 4 contains 17 species found in almost every quadrat, and can be considered the ubiquitous coastal sand rainforest species. The species with the highest frequency scores of the study, namely *Diospyros geminata, Drypetes deplanchei, Pouteria sericea, Exocarpos latifolius* and *Jasminum simplicifolium*, are members of this species group. Species group 5 comprises 16 species that are widespread but occur less frequently than group 4 members. Representatives are *Rapanea* spp., *Mimusops elengi* and *Pleiogynium timorense*.

Ordination results are shown in Figure 4 for species and Figure 5 for quadrats. The quadrat ordination diagram shows quadrat group 1 as a distinct cluster along positive values of the x-axis, with the remaining quadrats forming a series along the y-axis. Quadrat group 1 is correlated with the impeded drainage vector, and orthogonally with the flat morphology and dense vegetation vectors. The separation between quadrat group 1 and the remaining quadrat groups corroborates the clear demarcation of these communties shown in the classification results. The remaining series of quadrats are

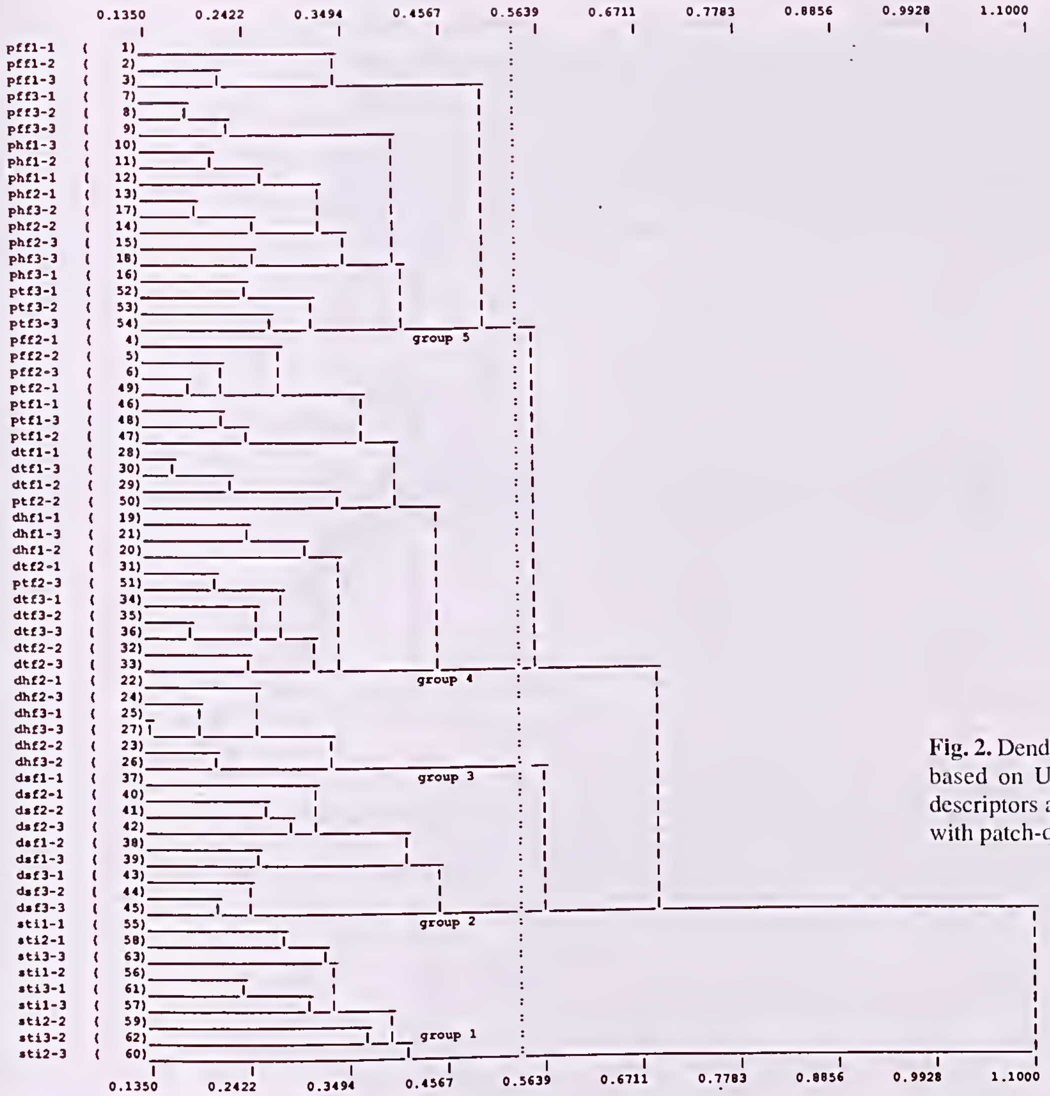

Fig. 2. Dendrogram of 63 quadrat samples, based on UPGMA fusion. The quadrat descriptors are shown in Table 1, suffixed with patch-quadrat number.

arranged along the Y-axis. Quadrat groups 2 and 3 are located at positive Y-axis values, correlated with swales and dense vegetation vectors. Quadrat groups 4 and 5, located at negative Y-axis values, correlate with foredune geomorphology, high exposure, scattered vegetation and elevated relative height vectors. The vectors latitude and distance to h.w.m. were poorly correlated with the quadrat and species groups.

Species groups show a similar pattern to the quadrats, located along the y-axis and at positive values of the x-axis. However, the species pattern is more diffuse than the quadrat pattern, due to the presence of a cloud of species located around the origin. These ubiquitous species are members of species groups 4 and 5, which exhibit little correlation with the environmental vectors. Species group 1 occupies the same space as quadrat group 1. Species group 2 occupies a broad sweep of space at positive x-axis values, spreading towards quadrat group 1, in which they were recorded sporadically. Species group 3 occupies similar space to quadrat group 5.

Discussion

This study detected strong local-scale patterns of species distribution and abundance in the coastal rainforest of Shoalwater Bay. The patterns show correlation with a number of environmental variables.

The strongest environmental variable was impeded drainage, correlated with species group 1 and quadrat group 1. The occurrence of the emergent sclerophyll species *Corymbia tessellaris* and *Melaleuca leucadendra*, the palm *Livistona decipiens* and a ground layer of *Cyperus* impart a distinctive structure to this community, which was clearly visible in the aerial photograph analysis. The impeded drainage is due to the proximity of underlying mudflats to the soil surface (Grinrod & Rhodes 1984, Cook & Polach 1973). Large amounts of litter accumulate from sclerophyll leaf and branch fall, creating a combustible ground layer in these patches. The presence of charred trunks of *Livistona*, *Corymbia* and *Melaleuca* indicate a dynamic community, with the fire tolerant emergents surviving the fire sensitive understorey rainforest species, and a re-invasion from surrounding rainforest of the fire sensitive species during fire free periods.

```
               Group 2          Group 5          Group 4        Group 3    Group 1

            EBOAACSCSPFTTC|PGMBFCAPADGRCCPA|PEDDJAPCCETMJMXIR|PSSACCACGHPN|LCMCAP
            url1lit1taieui|leirieianeeauasc|oxiraloaalraaiyxa|aaemaylalolo|ioeyci
            rieyyseerncrrs|eimecldvcnippnyr|looyseurpaoysclop|rrcyscppyyet|vrlpat
            odaxxsrrydumrs|gjuyutieidtaatco|ycspmctipeptmrora|scaeslhpcaue|iyaect
            flpsroqtppoppo|tseorpraudcvaodl|nlgdscsosmsddmoqc|pvecpceltaom|dtledf
            aeapupuosapoub|ialbuaauniyandaa|iaeeioeveeciiivur|lilouoxurupi|eeegie
            linisaaminprbl|mlelbncscsmraope|ttmpmnraplasdnaea|amlnbpccispc|csulsr
            ccicccdeldopeo|oinoiieticoicrhv|iiilpnitianpyutes|eiigereiftor|iscopr
  ------------+-----------------------+---
  pff1-1                  |*   ** *  * * *   ******* ****  ** ******** ** |    *
  pff1-2        *         |*** ** *  ****    *********  *  **  *** *   *  |
  pff1-3                  |*** ** * *  **    ********* ** *** ****     *  |     *
  pff3-1                  |*  *     * **    **************        **      |
  pff3-2                  |*  *     * **    ******* *****         **      |
G pff3-3                  |* ** *   * **    *************         **      |
R phf1-3             *    |**   ***    *    **************    *****    *  |     *
O phf1-2                  |*** ****    * *  ************* *   *****    *  |
U phf1-1                  |**   * * *  *    **************    * ****   *  |
P phf2-1                  |**   * * * ** *  *************       ****      |
  phf3-2                  |**     * * **    *************       ****   *  |
5 phf2-2                  |*    * * ****    ************** *    **** **   |
  phf2-3                  |**   * *    * *  ************** *    ***** *   |
  phf3-3                  |*    ***  *** *   *** ********      * ****     |
  phf3-1                  |***    * *  *     ********* ***    ****        |
  ptf3-1          *       |****  ** * *** *  ************* *   ***        |
  ptf3-2                  |****  ** * ***   ******* *******    ****  **   |
  ptf3-3        **        |****     * ****  ******* ***** *    ********   |
  --------------+---------- ---------- --------+----
  pff2-1       *          |* ** * *    *     ****** ** ** ***  *** *  *   |     *
  pff2-2       *  *       | ** ** *   **  * *********  ******  *** *    * |     *
  pff2-3       *          | **  *  *   **   ******* * *******  ***      * |
  ptf2-1      **          |***  *           *****************  ***      * |     *
  ptf1-1                  |* **  ***   ***  ***************** * **     ***|
G ptf1-3                  | *** * *    *    ********** ******  ***      * |
R ptf1-2       *          |*****   *   **   ********** ******  **       * |   *
O dtf1-1     **           |**** **     * ** *****************  * * **     |    *
U dtf1-3     *            |* **       ** ** *****************  ******     |    *
P dtf1-2        *         |****       *  ** ********* ******* *** ***     |
  ptf2-2        **        |*  *      *** *  *************  **  *** **   **|
4 dhf1-1      *   *       |* * ******  **   *****************  *   *    **|
  dhf1-3      * *     *   |* * **** * **    *****************  ***      **|
  dhf1-2     ** * *       |*** ******* ***  ****************       *      |
  dtf2-1      ***         | **  ***  ****** *****************    * *   ***|
  ptf2-3      ***         | ** ** *   ***** *****************  ***  *   **|
  dtf3-1     ** *   *     |***   *    ***** ***************** *    **   **|
  dtf3-2        **        |*********  ***** ************** ** * *      ***|
  dtf3-3        *         |*****  **  ***** ************** **    *     ***|
  dtf2-2     ***** ***    |***** **   ***** ****************       *    **|
  dtf2-3      * *  ** *   |***  ***   ***** ************* ***  * **     **|
G ------------+-------- -------- ------+---
R dhf2-1        * *       |*** *****  *  *  ************* **         *    |
O dhf2-3    * * * **     *|*** ****    ***  ******* *****  *       ** *   |
U dhf3-1      * * *      *|*** *****   *    *************  *              |
P dhf3-3      * * *       |*********   *  * *************  *        *     |
  dhf2-2        *         |  ** ***  ****   *** ***  ***  **         **   |
3 dhf3-2        *         |**** ****   *  * ******* ****   *              |
  ------------+-------- -------- ------+---
  dsf1-1    ***   *     * |*******       *  ***** ******* ***  **  **     |
G dsf2-1    ***** *    ***|* ** **     *    *********** * ***  **         |
R dsf2-2     ** *       **|* *** * **  *    ************* **              |
O dsf2-3    *****   *  ***|*******          ***** *** * * **   *          |
U dsf1-2    ***      *    |*******    ** **  ***********  ***             |
P dsf1-3    ***      *    |*******  *  * ** ******  **** ****        *    |
  dsf3-1    *******   *  *|******* *** *  * *****************             |
2 dsf3-2    ****** *  * * |******* *** *    ********* *******             |
  dsf3-3    ***** **    **|******* *** *    ********* *** ***             |     *
  ------------+-------- -------- ------+---
  sti1-1    **            |**** * *   ** ** ****** *  *******   *         |******
G sti2-1                  |*  **      ****  ******     ** * *             |*** **
R sti3-3             **   |*          ***   * * ** **  ** ***             |******
O sti1-2    *   *    *    |*    ** *  ** *  ******   * ******             |******
U sti3-1    *             |*  **      ** ** **  *  * * ** ***             |******
P sti1-3    *             |           ** *  ** **  *   *  ***             |******
  sti2-2    *        **   |** *       **    ****   **   * *    *          |*** **
1 sti3-2    *             | **  * *    * *  ***  *     ****               |******
  sti2-3    *             |   **       ** * **         ** ***        *     |*** **
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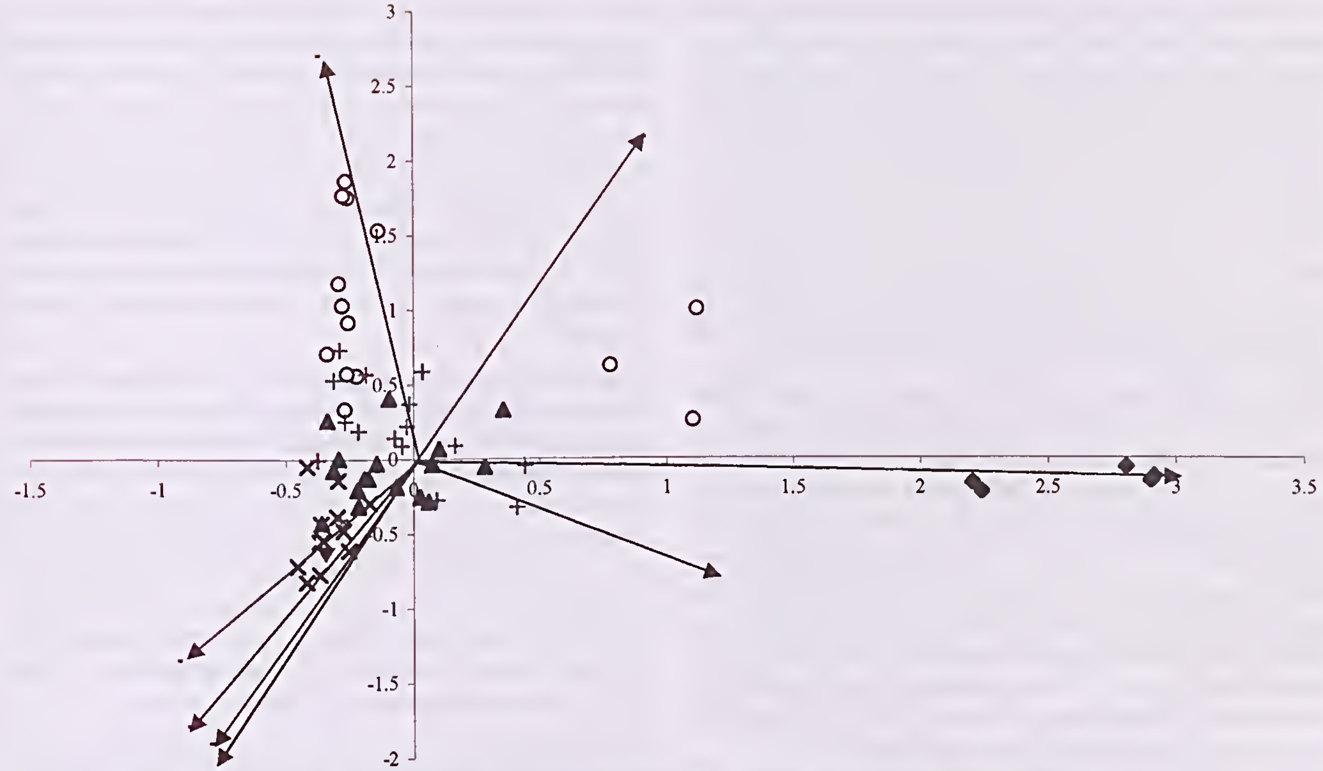
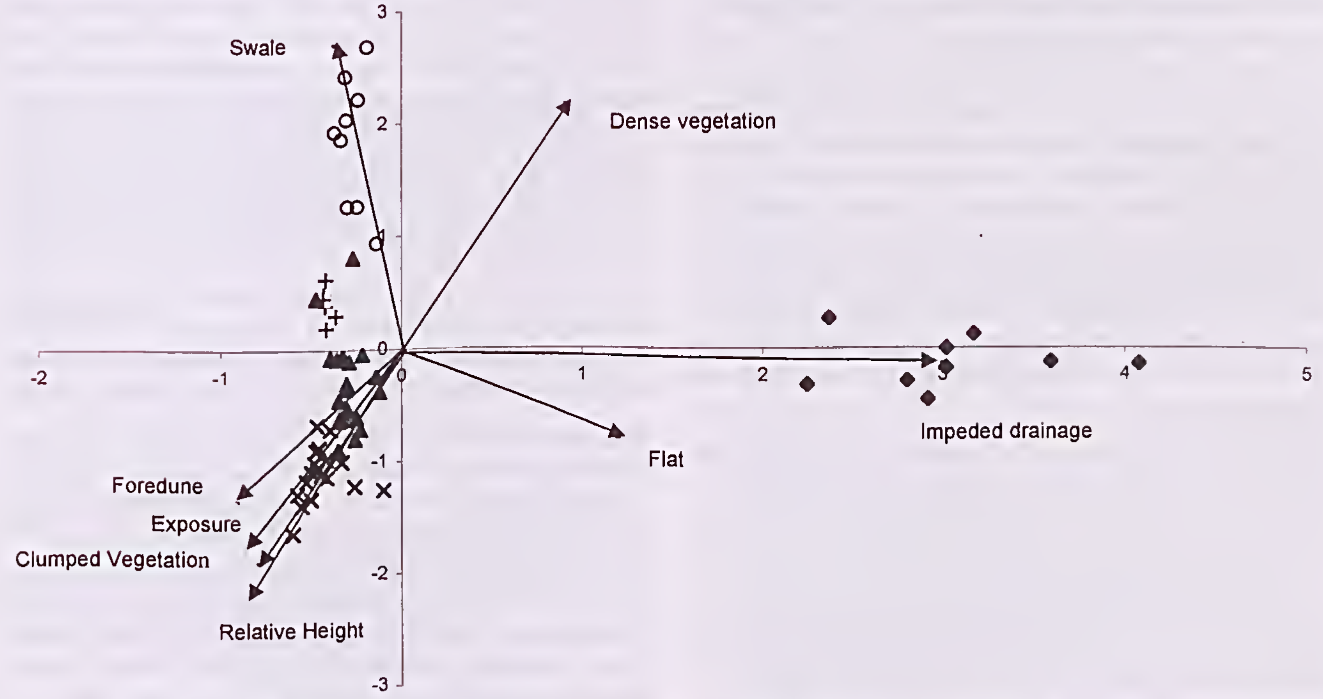
Fig. 3. Two-way table of classification results for 63 quadrats and 65 species. Quadrat labels as for Figure 2. Species labels are listed in Appendix 1.



Ordination results for species showing species membership of five species classification groups. Vectors x 3.

◆ Species Group 1 ○ Species Group 2 ✕ Species Group 3 ▲ Species Group 4 + Species Group 5

Fig. 4.



Ordination results for quadrats showing quadrat membership of five quadrat classification groups. Vectors x 3.

◆ Quadrat Group 1 ○ Quadrat Group 2 + Quadrat Group 3 ▲ Quadrat Group 4 ✕ Quadrat Group 5

Fig. 5.

All species appear to be able to tolerate periods of shallow submersion. This forest was classified as a mixed forest (Adam 1992), and exhibits a clear floristic and physical difference to the remaining vegetation. The sclerophyll emergent layer and rainforest understory are akin to wet sclerophyll forests of more temperate regions (Specht 1981, Adam 1992). Analogous communities in Queensland coastal rainforest have been documented by Tracey (1992) where beach ridge and swale systems support mixed vegetation, where *Melaleuca*, *Corymbia* and *Acacia* form a prominent sclerophyll component of the rainforest community. The impeded drainage of this community, which favours *Livistona decipiens* and *Cyperus eglobosus*, bears close resemblance to the communities described in Webb's (1968) subtropical swamp series, where notophyll palm forest gives way to sclerophyll sedge forest as drainage becomes increasingly impeded. Batianoff and McDonald (1980) documented a similar forest on the Capricorn Coast, where the *Livistona–Melaleuca–Eucalyptus (Corymbia)* assemblage occupied large areas of the extensive parallel beach ridge systems. Melzer et al. (1993) identified a similar community in the Shoalwater Bay area, where poorly drained coastal and inland dunes systems support communities dominated by *Livistona decipiens* and *Euroschinus falcata*.

The remaining free-draining quadrats appear in ordination as a continuum, ranging from dense, low rainforest in swales to scattered wind-sheared thickets on foredunes. This series of quadrats lacked sclerophyll species, and the decrease in stature from low forest to thickets was correlated with relative landform height and exposure. They show a gradual turnover of species and change in physical structure along the environmental gradients.

Group 2 and 3 quadrats, representing the tallest and least exposed rainforest facies, were classified as low microphyll vine forest (LMVF) according to the criteria of Webb (1968). This vegetation resembled the protected rainforest located behind foredunes as described by Queensland coastal rainforest studies (Lavarack & Godwin 1987, Tracey 1982). This vegetation is closely allied with the low closed forests identified by Batianoff and McDonald (1980). In common with that study, the low closed forests were located between a *Livistona–Melaleuca–Corymbia* association and foredune heaths and scrubs.

Group 4 and 5 quadrats were classified as microphyll vine thicket (MVT). The MVT vegetation is similar to that recorded in many locations along the Queensland coastline. Lavarack and Godwin (1987) described frontal dunes covered by dense vine thicket, and noted the reduction in canopy height due to exposure to onshore winds. Similarly, Hopkins et al. (1979) describe wind sheared beach scrub at Cowley Beach. Batianoff and McDonald (1980) have documented foredune closed and open heath/scrub on the Capricorn Coast. Along the northern areas of the NSW coastline, similar communities are described by Floyd (1990b), where the *Cupaniopsis anacardioides* alliance forms low, wind-moulded scrubs on the coastal margins of rainforest.

Group 4 quadrats represent the largest aerial extent of rainforest that is of intermediate stature along the LMVF/MVT continuum. Fifty-seven of the 65 species recorded in the study are found in group 4 quadrats. Environmental variables show a moderate level of exposure, and an intermediate relative height. As the exposure and relative height of the landform increase, increasing patchiness, a larger vine component and a decrease in canopy height are apparent. This vegetation represents the extreme littoral expression of rainforest in central Queensland, and was recorded in group 5 quadrats.

The species turnover along the LMVF/MVT gradient occurs against a background of stochastic species occurrence, represented by species groups 4 and 5. The range of environmental factors at the study site had little effect on these species groups, and they form a consistent part of the recorded flora. Floristically, this vegetation could be summarised as a *Diospyros–Drypetes–Pouteria–Exocarpos* association for both the LMVF and the MVT. Against this variable background of ubiquitous species, two correlations were distinguished, one comprising a group of species restricted to the LMVF, and the other restricted to the MVT.

Species group 2 was concentrated in the LMVF, and absent from the MVT. The low relative heights of the landforms supporting the LMVF infer proximity to subsoil moisture, and thus more mesic species persist here. Lower salt loads in the protected hinddune and swale locations would also allow salt sensitive species to persist.

Species group 3 is closely related to the exposed situations on elevated landforms of the MVT. Many of the species are vines, favoured by a low and easily accessible canopy, and high sub-canopy light levels where the vegetation is clumped. Vines may also form the extreme leading edge of the foredune vegetation, where a tangle of leafless or succulent vine species such as *Cassytha pubescens* and *Sarcostemma viminale* create the lowest part of the canopy. Species of the MVT are generally evergreen, maintaining a consistent canopy cover in all seasons, which is essential for canopy integrity under the constant stress of onshore salt-laden winds. Although the Shoalwater Bay coastline is within the environmental range for deciduous rainforest, deciduous species are restricted to the taller and more protected forests.

Two structural types of the MVT are evident, based on the continuity of vegetation cover. The patchy type, consisting of discrete clumps of rainforest separated by bare sand areas, were floristically indistinguishable from the continuous MVT type where moderate exposure and elevation were recorded, as in quadrat group 4. At higher levels of exposure and elevation, only the patchy type was recorded, and quadrat group 5 contains only this form of MVT. There are two hypotheses regarding the formation of the patchy type:

(i) the original establishment of the rainforest in areas that show strong correlation with high exposure and elevated landforms occurred in such a way that either establishment never proceeds to colonise all the area, or is in the process of continuing to colonise the area. The study results do not preclude the former, however the latter is unlikely. No rainforest seedling germination was observed in the very exposed sand areas which lack organic material. However, the regeneration of rainforest under the clumps of the patchy vegetation is proceeding in a similar manner to the closed forest, where a deep peat layer moderates soil temperature and moisture in the shady understorey. If establishment is patchy in nature, it has remained so at least in the recent past.

(ii) that original establishment was complete, and that a decay process is occurring under the stresses that prevail in areas where clumped vegetation occurs. There is no evidence however of dead rainforest species in the inter-patch areas, and the boundary of each clump appears to be stable, neither relinquishing species from the edges, nor increasing the area by colonisation. Environmental conditions at the study site may have varied since a complete establishment event, resulting in the loss of rainforest area. It may have reached an equilibrium, or be proceeding at very slow rates. Floyd (1990a) considered the regeneration of littoral rainforest of N.S.W. coastal stands to be inhibited by the change in climate since the original establishment events of the Holocene. It appears likely that a similar climatic deterioration has resulted in conditions less favourable for the establishment of coastal rainforest in the study area, and possibly severe enough to degrade the most vulnerable areas. Damage from intense meteorological events may be one of the destructive forces responsible for the partial loss of rainforest areas in clumped vegetation. The establishment of a more benign climate may allow regeneration of the bare areas.

Acknowledgements

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References

Adam, P. (1992) *Australian rainforests* (Clarendon Press: Oxford).

ABARE, AGSO & BRS (1993) *Shoalwater Bay Military Training Area Resource Assessment* (AGPS: Canberra).

Batianoff, G. & McDonald, T. (1980) *Capricorn Coast sand and headland vegetation* (Botany Branch, Department of Primary Industries: Brisbane).

Baur, G. N. (1962) Forest Vegetation in north-eastern New South Wales. *Research Note 8* (Forestry Commission of NSW: Sydney).

Belbin, L. (1993) *PATN Technical Reference Manual* (CSIRO Division of Wildlife and Ecology: Canberra).

Bowman, D.M.J.S. (1992) Monsoon forests in north-western Australia. II. Forest-savanna transitions. *Australian Journal of Botany* 40: 89–102.

Bowman, D.M.J.S. (2000) *Australian rainforests: Islands of green in a land of fire* (Cambridge University Press: Cambridge).

BPA (1979) *Capricorn Coast beaches* (Beach Protection Authority: Brisbane).

BPA (1982) *Cyclones and their effects on beaches* (Beach Protection Authority: Brisbane).

Byrnes, N.B., Everist S.L., Reynolds, S.T., Specht, A. & Specht, R.L. (1977) The vegetation of Lizard Island, North Queensland. *Proceedings of the Royal Society of Queensland* 88: 1–15.

Cook, P.J. & Polach, H.A. (1973) A chenier sequence at Broad Sound, Queensland, and evidence against a Holocene high sea level. *Marine Geology* 14: 253–268.

Dick, R.S. (1975) The climate of Australia: According to Koeppens principles of definition. *Queensland geographical Journal* 3rd Series, Vol. 3.

Dunlop, C.R. (1976) Botany of Maria Island, Gulf of Carpentaria. *Northern Territory Botanical Bulletin* 2: 1–14.

Dunlop, C.R., Latz, P.K., & Maconochie, J.R. (1976) A botanical survey of Elcho Island. *Northern Territory Botanical Bulletin* 1: 1–56.

Floyd, A.G. (1990a) *Australian rainforests in New South Wales I* (Surrey Beatty & Sons: Chipping Norton).

Floyd, A.G. (1990b) *Australian rainforests in New South Wales II* (Surrey Beatty & Sons: Chipping Norton).

Forster, P.I., Bostock, P.D., Bird, L.H. & Bean A.R. (1991) *Vineforest plant atlas for South-East Queensland* (Queensland Herbarium: Indooroopilly).

Gillison, A.N. (1987) The 'dry' rainforests of Terra Australis. Pp. 350–355 In G. Werren & A.P. Kershaw (eds), *The rainforest legacy. Australian national rainforests study 1* (Australian Government Publishing Service: Canberra).

Harden, G.J. (Ed.) (1990-1993) *Flora of New South Wales* Vols 1–4 (New South Wales University Press: Kensington).

Hopkins, M.S., Graham, A.W. & Murtha, G. (1979) *The vegetation of Cowley Beach area, joint tropical trials research establishment, North Queensland.* Technical Memorandum 79/13, CSIRO Institute of Earth Resources, Division of Land Use Research, Canberra.

Lavarack, P.S. & Godwin, M. (1987) Rainforests of northern Cape York Peninsula. Pp. 201–226 in G. Werren and A.P. Kershaw (eds), *The rainforest legacy. Australian national rainforests study 1* (Australian Government Publishing Service: Canberra).

Melzer, R., Barry, S. & Kershaw, N. (1993) *Research report 8: Flora survey: Shoalwater Bay Military Training Area* (Commonwealth Commission of Inquiry, Shoalwater Bay, Capricornia Coast: Brisbane).

Morrision, D.A., Le Brocque, A.F. & Clarke, P.J. (1995) An assessment of some improved techniques for estimating the abundance (frequency) of sedentary organisms. *Vegetatio* 120: 131–145.

Outhred, R.K. (1984) Semi-quantitative sampling in vegetation survey. Pp. 87–100 in K. Myers, C.R. Margules & I. Musto (eds), *Survey methods for nature conservation* (CSIRO: Canberra)

QDEH. (1994) Introducing dry rainforests (Queensland Department of Environment and Heritage: Brisbane).

Russell-Smith, J. & Dunlop, C. (1987) The status of monsoon vine forests in the Northern Territory: a perspective. Pp. 227–288 in G. Werren and A.P. Kershaw (eds), *The rainforest legacy. Australian national rainforests study 1* (Australian Government Publishing Service: Canberra).

Specht, R. L. (1981) Foliage projective cover and standing biomass. Pp. 10–21 in A.N. Gillison and D.J. Anderson (eds), *Vegetation classification in Australia* (CSIRO/ANU Press: Canberra).

Specht, R.L., Salt, R.B., & Reynolds, S.T. (1977) Vegetation in the vicinity of Weipa, North Queensland. *Proceedings of the Royal Society of Queensland* 88: 17–38.

Ter Braak, C.J.F. (1988) *Canoco — a FORTRAN program for Canonical Community Ordination* (Microcomputer Power: New York).

Tracey, J.G. (1982) *The vegetation of the humid tropical region of north Queensland* (CSIRO: Melbourne).

Webb L.J. (1968) Environmental relationships of the structural types of Australian rain forest vegetation. *Ecology* 49: 296–311.

Young, P.A.R. and McDonald, W.J.F. (1987) The distribution, composition and status of the rainforests of southern Queensland. Pp. 119–141 in G. Werren and A.P. Kershaw (eds), *The rainforest legacy. Australian national rainforests study 1* (Australian Government Publishing Service: Canberra).

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Appendix 1:

Vascular species recorded in coastal rainforest of Shoalwater Bay. Species group and two-way table codes are shown for species recorded in quadrat results.

Dicotyledons	**Group**	**Code**
Anacardiaceae		
Euroschinus falcatus	2	Eurofalc
Pleiogynium timorense	5	Pleitimo
Annonaceae		
Polyalthia nitidissima	4	Polyniti
Apocynaceae		
Alyxia ruscifolia	2	Alyxrusc
Alyxia spicata	2	Alyxspic
Carissa ovata	4	Carisovat
Parsonsia plaesiophylla	3	Parsplae
Asclepiadaceae		
Sarcostemma viminale subsp. *brunonianum*	3	Sarcvimi
Gymnanthera oblonga		
Hoya australis subsp. Australis	3	Hoyaaust
Secamone elliptica	3	Secaelli
Bignoniaceae		
Pandorea pandorana	2	Pandpand
Capparaceae		
Capparis arborea		
Capparis lucida	3	Cappluci
Capparis sepiaria	4	Cappsepi
Celastraceae		
Elaeodendron melanocarpum	4	Elaemela
Maytenus disperma	4	Maytdisp
Pleurostylia opposite	3	Pleuoppo
Combretaceae		
Terminalia porphyrocarpa	2	Termporp
Ebenaceae		
Diospyros geminata	4	Diosgemi
Euphorbiaceae		
Breynia oblongifolia	5	Breyoblo
Bridelia leichhardtii	2	Bridleic
Drypetes deplanchei	4	Drypdepl
Fabaceae		
Abrus precatorius		
Flacourtiaceae		
Xylosma ovatum	4	Xyloovat
Lauraceae		
Cassytha pubescens	3	Casspube
Lecythidaceae		
Planchonia careya		
Loganiaceae		
Strychnos psilosperma	2	Strypsil
Loranthaceae		
Amyema congener subsp. *congener*	3	Amyecong
Dendropthoe glabrescens		
Meliaceae		
Turraea pubescens Benth.	2	Turrpube
Menispermaceae		
Tinospora smilacina		
Stephania japonica var. *discolor*		
Mimosaceae		
Acacia disparrima	1	Acacdisp
Moraceae		
Ficus rubiginosa	5	Ficurubi
Ficus opposita var. *opposita*	2	Ficuoppo
Trophis scandens	4	Tropscan
Myoporaceae		
Myoporum acuminatum		
Myrsinaceae		
Rapanea variabilis	5	Rapavari
Rapanea crassifolia	5	Rapacras
Myrtaceae		
Corymbia tesellaris	1	Corytess
Gossia bidwillii		
Melaleuca leucadendra	1	Melaleuca
Oleaceae		
Olea paniculata	2	Oleapani
Jasminum simplicifolium subsp. *australiense*	4	Jasmsimp
Jasminum didymum subsp. *didymum*	4	Jasmdidy
Notelea microcarpa var. *microcarpa*	3	Notemicro
Passifloraceae		
Passiflora aurantia var. *aurantia*		
Pittosporaceae		
Pittosporum ferrugineum	1	Pittferr
Rhamnaceae		
Alphitonia excelsa	3	Alphexce
Rubiaceae		
Aidia racemosa	5	Aidirace
Cyclophyllum coprosmoides	3	Cyclcopr
Cyclophyllum odoratum	5	Cantodor
Psychotria daphnoides	5	Psycdaph
Ixora queenslandica	4	Ixorquee
Pavetta australiensis	5	Paveaust
Rutaceae		
Geijera salicifolia	5	Geijsali
Acronychia laevis	5	Acrolaev
Micromelum minutum	5	Micrminu
Glycosmis trifoliata	3	Glyctrif
Santalaceae		
Exocarpos latifolius	4	Exoclati
Sapindaceae		
Alectryon connatus	4	Alecconn
Cupaniopsis anacardioides	5	Cupaanac
Elattostachys xylocarpa		
Sapotaceae		
Pouteria sericea	4	Poutseri
Mimusops elengi	5	Mimuelen
Sterculiaceae		
Brachychiton australis		
Sterculia quadrifida	2	Sterquad
Ulmaceae		
Celtis paniculata	5	Celtpani
Trema tomentosa var. *tomentosa*		
Verbeneceae		
Clerodendron floribundum	2	Clerflor
Viscaceae		
Viscum articulatum		
Vitaceae		
Cissus oblonga	2	Cissoblo
Cissus opaca	2	Cissopac
Monocotyledons		
Arecaceae		
Livistona decipiens	1	Livideci
Cyperaceae		
Cyperus eglobosus	1	Cypeeglob
Luzuriagaceae		
Geitonoplesium cymosum	5	Geitcymo
Orchidaceae		
Cymbidium canaliculatum		
Dendrobium bowmanii		
Dendrobium discolor	5	Denddisc
Poaceae		
Ancistrachne uncinulata	5	Anciunci

Habitat, distribution and the phytogeographical affinities of mosses in the Wet Tropics bioregion, north–east Queensland, Australia.

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Abstract: A checklist of the mosses (Bryophyta) of the Wet Tropics bioregion, north-east Queensland is presented. Included is an update on the taxonomy of species, listing a total of 408 taxa. The habitat and distribution patterns of species within the area and in Australia, together with information on the phytogeographical affinities of these taxa in related areas beyond Australia, are discussed.

***Cunninghamia* (2004) 8(3): 371–408**

Dedication

The authors present this work as a tribute to the memory of the late **Ilma Stone (1913–2001)** and **Heinar Streimann (1938–2001)**, whose work in the area formed the basis for these studies.

The work began in the 1980s, between 1984 and 1998 with Ilma Stone, whose taxonomic studies and data from collections made in the area over many years were immeasurable. Heinar Streimann assisted later in the 1990s, with various taxonomic contributions and data from many collections. Without their assistance and knowledge, the work would not have been written. Their deaths in January 2001 and August 2001 respectively were a serious and tragic blow to Australian bryology.

Introduction

Mosses and liverworts, the major groups of bryophytes, are a significant component of the biodiversity in the Australian wet tropics, in north-east Queensland, occurring in all ecosystems as colonisers of soil, rocks, fallen logs, and as epiphytes and epiphylls. While much attention has been paid to the vascular plants, vegetation types and ecology of tropical north-east Queensland (Tracey & Webb 1975, Kershaw 1978, Tracey 1982), R.M. Schuster (in Keto & Scott 1986) emphasised the importance of bryophytes in the region and criticised the paucity of studies.

Many mosses from north-east Queensland were described and published at the end of the 19th and beginning of the 20th century (Bailey 1893, 1913; Watts & Whitelegge 1902, 1906; Brotherus & Watts 1918; Dixon 1938, 1942; Bartram 1952). Ramsay et al. (1987) estimated the moss flora in the ‘wet tropical region of north Australia’ (approximately equivalent to the area under discussion) at about 325 species, representing one quarter of the total species for Australia. There were about 114 Australian endemics present, of which 50–60 were thought to be endemic to the region (Ramsay et al. 1987). The areas of greatest species richness were in the rainforests on the high mountain peaks, and on the Atherton Tableland.

Windolf (1987) estimated there were approximately 173 liverwort species in the region, with 20% of these being endemic (Hicks 1986). Recent estimates put the liverwort figure at over 300 taxa (D. Meagher pers. comm.).

Bryophytes in rainforests

For bryophytes, rainforests provide niches largely absent in other communities (Pócs 1982, Richards 1984, Gradstein 1992) including soil, earth banks, rocks, fallen trees and living roots on the forest floor, and further upwards, the bases, buttress roots and trunks of rainforest trees. Habitats in the canopy include lianes, twigs and branches for epiphytic species, while leaf surfaces provide habitats for epiphyllous species. Bryophytes on rotting logs maintain a moist regime that enhances decomposition and recycling through the activities of fungi and other microorganisms. They play an important role in ecological succession by protecting soil from erosion and providing moist beds for seeds to germinate. In all rainforest environments, bryophytes provide microhabitats and refugia for invertebrates and microorganisms, and sites for egg-laying and nurseries for insect larvae. Growth forms such as mats, cushions or pendents provide surfaces important for harvesting water from cloud and storing minute quantities of nutrients from exudates and droppings of insect larvae that are released slowly as leachates over time. Bryophytes control and reduce runoff by gradually releasing moisture during dry periods, maintaining humidity in the forest. They also contribute to humus accumulation, all important to the maintenance of the rainforest as an ecosystem.

History of rainforests in north-east Queensland

The history of rainforest bryoflora is closely associated with the history of Australian rainforests, and in north-east Queensland there is evidence of a long ancestry (Webb et al. 1986, Hill 1994, Webb & Tracey 1994, Martin 1998). Original Gondwanan-derived primitive angiosperm species survive in the rainforests of tropical Queensland. In addition, some of the oldest living forms of our present-day dry-adapted sclerophyllous vegetation and their related ecosystems also survive there. Barlow and Hyland (1988) summarised the important paleogeographic and paleoclimatic events that have led to 'an intricate pattern of humid forest communities which show significant differences in composition, age, endemism, relictuality and richness'. Martin (1998) provided additional evidence, based on palynological studies, of the Tertiary climate in Australia and stated that the precipitation in north-east Australia remained above critical levels for rainforest throughout the Tertiary and most of the Quaternary, enabling the region to be a refuge for many rainforest taxa. Australian rainforests reached their maximum development in the mid Tertiary, thereafter, increasing aridity resulted in reduction of rainforest areas and their retreat to areas of higher rainfall (Frakes 1999).

Rainforests in Australia

In Australia, 'rainforest' is a generic term and includes evergreen forests along the eastern coast (including Tasmania) and seasonally deciduous forests of the north (Lynch & Neldner 2000). Descriptors of rainforests, such as 'tropical', 'sub-tropical', 'monsoonal' and 'temperate' that relate to climate (latitude), and 'montane' and 'sub-montane' that apply to altitude (Beadle & Costin 1952), have application in other regions of the world but do not adequately describe the range of rainforest types found in Australia.

Webb (1959) recognised twenty rainforest structural types and classified Australian rainforests on the basis of structure, based on leaf size, seasonality of leaf fall, presence of other life-forms etc., which he later correlated with environmental factors (climate, soil nutrient status) (Webb 1968). Type descriptions of 'vine forests' and 'vine thickets' (depending on canopy height) are based on leaf sizes (microphyll, notophyll and mesophyll), deciduousness, and structural complexity. The floristic composition of each forest type varies from one locality to another as a result of past rainforest expansions and contractions due to palaeoclimatic events (Martin 1994). Typically, boundaries between structural types are not clear, although distinctions between rainforest and sclerophyll (eucalyptus) communities are generally abrupt, controlled by fire (Adam 1994).

The Wet Tropics bioregion

The Wet Tropics bioregion (Satler & Williams 1999) is situated along the coast of north-east Queensland, extending south from near Cooktown (15° 35' 46"S, 145°15'20"E) to just north of Townsville (19°23'51"S, 146°29' 28"E), a distance of over 500 km along the Australian coast (Goosem et al. 1999). It lies to the east of the Great Dividing Range and consists of a coastal plain dissected by ridges of the Eastern Escarpment and associated coastal ranges. Along its western flank, it borders the Einasleigh Uplands bioregion, and at its southern extremity, the Townsville Plains province of the Northern Brigalow Belt (Sattler & Williams 1999). To the north, the Wet Tropics links to the remote Cape York Peninsula bioregion. The Wet Tropics bioregion covers approximately 1% of Queensland, with an area of 1 849 725 ha (Goosem et al. 1999). A map of the region is shown in Figure 1.

The Wet Tropics is dominated by forested mountains and ranges, with areas of high plateau. Inland from Daintree (lat.16°S) lies the Mt Windsor Tableland (800–1360 m), and extending westwards from the Bellenden Ker Range, the Atherton Tableland (700–1200 m). Transects (see Fig.1, Fig.2 A–C) across Mt Windsor Tableland to the coast, across the Atherton Tableland and the Bellenden Ker Range to the coast, and through Cardwell Range to Hinchinbrook Island, and the south-north profile (Fig.2 D) running through the major peaks and rivers, illustrate the diverse topography of the region (Figs 2 A–D).The Wet Tropics bioregion includes the highest mountains in Queensland — Mt Bartle Frere (1622 m) and Mt Bellenden Ker (1582 m) on the Bellenden Ker Range; Thornton Peak (1374 m), Mt Lewis (1224 m), and Mt Finnigan (1148 m) (Figs. 1 and mountainous Hinchinbrook Island, with Mt Bowen (1142 m) and Mt Diamantina (955 m), is also part of this assemblage. The Cooktown–Ingham massif containing these high peaks covers an area of approximately 360 × 80 km (Webb & Tracey 1981).

Physiography

The coastal massif and associated ranges form a more or less continuous belt along the eastern Queensland coast, and are igneous in origin. Rocky outcrops are common on mountains, and soils of the massif are primarily granitic. The underlying geology comprises mainly marine Silurian, Devonian and Carboniferous sediments of the Hodgkinson Formation (Arnold & Fawckner 1980). Barron River Metamorphics are exposed in valleys around Cairns, and south to Tully, and sandstones predominate near Cooktown (Wilmott & Stephenson 1989). The scoria cones, maars, obvious basalt flows and fertile basaltic soils of the Atherton Tableland represent volcanism dating from the late Tertiary and Quaternary and overlay a mainly metamorphic base. In some areas, basalt flows followed river systems and reached the coastal plain (Stephenson et al. 1980), although coastal lowland soils are mainly of alluvial and colluvial deposits, largely accumulated during the late Quaternary (Nott et al. 2001). Repeated coastal transgressions and retreat during the Quaternary led to the deposition of coastal and estuarine sediments in some areas, with the attainment of the present sea level approximately 6000 years ago. Large rivers — the Daintree, Bloomfield, Barron, Russell, Mulgrave, North and South Johnston, Tully and Herbert drain the region into the Coral Sea, with higher western areas draining south into the Burdekin River, and north to the Mitchell.

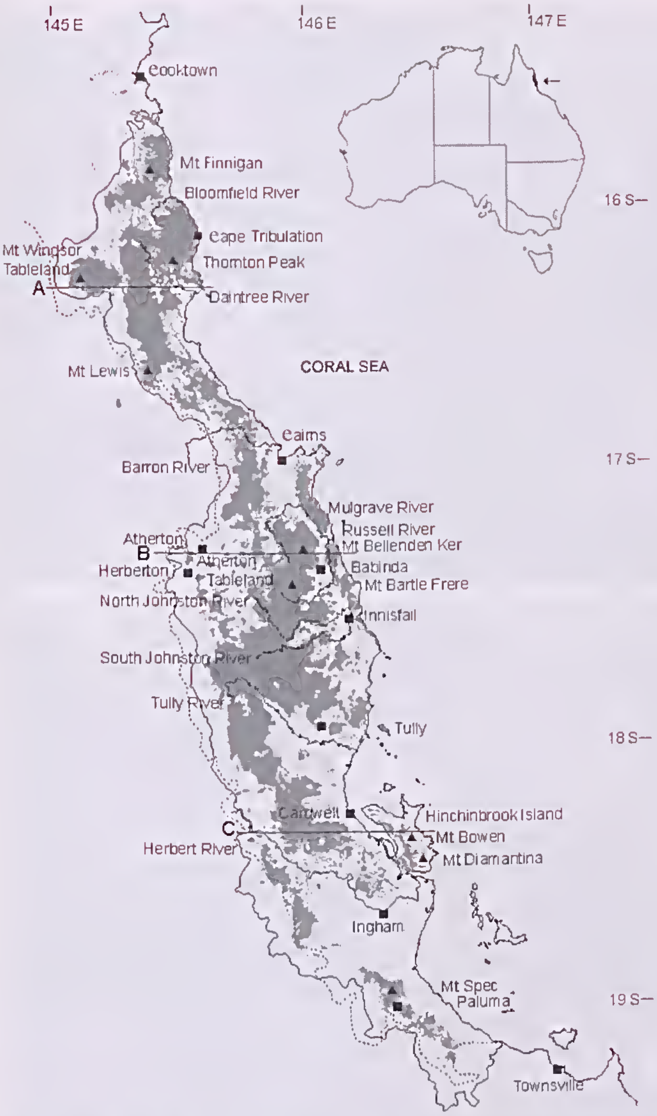


Fig. 1. The Wet Tropics bioregion, north-east Queensland. Dotted line represents the 1250 mm rainfall isohyet; shaded areas represent extant rainforest.

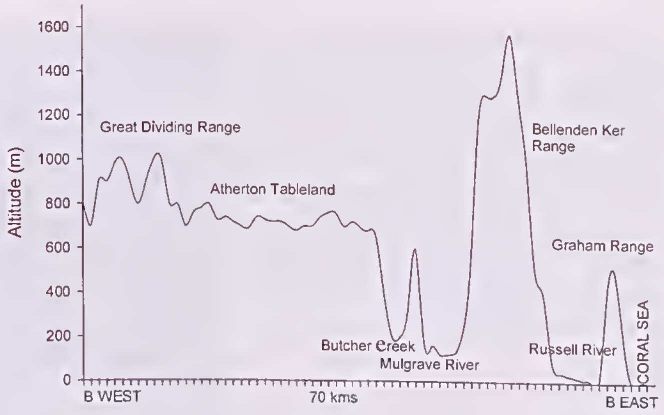


Fig. 2B. Transect across latitude 17 15' 45"S from Great Dividing Range to the east coast (70 km) (Division of National Mapping Topographic Map 1:100000 Series R631, Edition 2-AAS: Sheet 7963 Atherton and Sheet 8063 Bartle Frere).

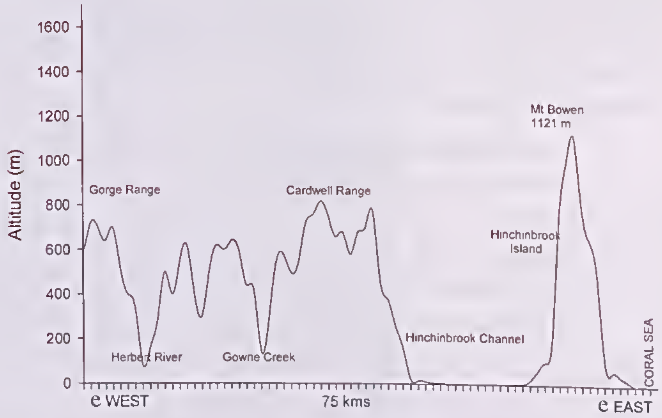


Fig. 2C. Transect across latitude 18°21'S from Gorge Range to Hinchinbrook Island (75 km) (Division of National Mapping Topographic Map 1:100 000 Series R631, Edition 2-AAS: Sheet 8061 Kirrama and Sheet 8161 Cardwell.)

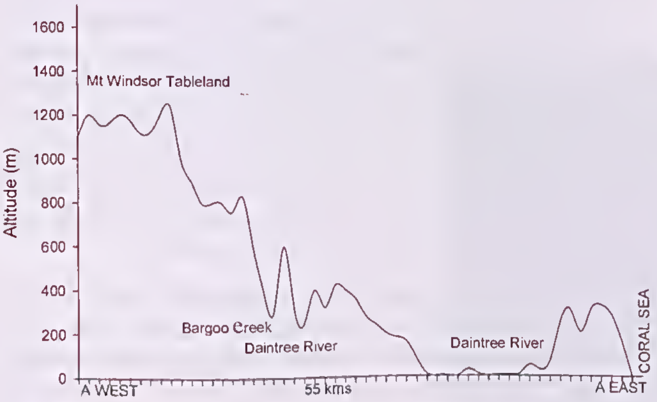


Fig. 2A. Transect across latitude 16°15' S from Mount Windsor Tableland to east coast (55 km) (Division of National Mapping Topographic Map 1:100000 Series R631, Edition 1-AAS: Sheet 7865 South Palmer River and Sheet 7965 Mossman.)

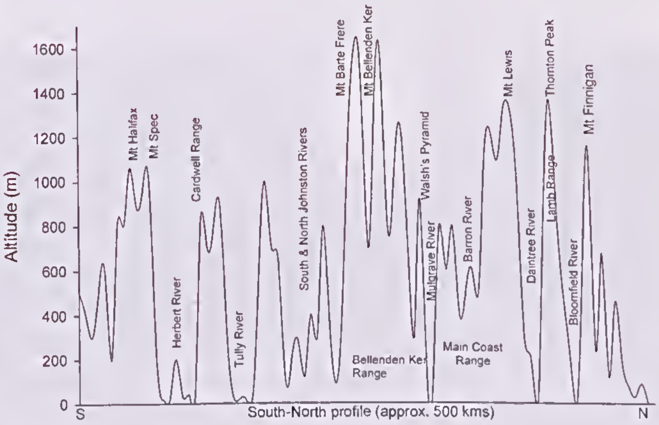


Fig. 2D. South-north profile through the Wet Tropics bioregion, showing major peaks and rivers. (Note the x axis is approximate.)

The Wet Tropics bioregion is subdivided into nine provinces (Fig. 3), reflecting differences within the landscape, generally associated with geology, geomorphology and climate. Goosem et al. (1999) provide descriptions of provinces (geology, landform, soils and vegetation) and associated regional ecosystems. Much of the bioregion incorporates the Wet Tropics of Queensland World Heritage Area (WTQWHA) (Satler & Williams 1999), recognised by the international community for the richness and diversity of its flora and fauna.

Climate

The climate generally results in two seasons, a separate wet season (December–April), with summer monsoons and occasional tropical cyclones, and an almost dry season (May–November) with occasional showers. Mean annual temperatures vary with topography, from 30°C in the tropical lowland to less than 10°C in montane areas (Webb 1968). Annual rainfall over the region is highly variable, strongly influenced by local topography, and declines towards the north and the south (Adam 1994). There are three locations on and around the high peaks where the rainfall can exceed an average of 3750 mm per annum:

- Thornton Peak, Mt Finnigan, Cape Tribulation (north of the Daintree River), and Mt Lewis (north west of Cairns);
- Mt Bartle Frere, Bellenden Ker and Babinda between the Mulgrave and Russell Rivers;
- lowland areas between the Johnston and Tully Rivers.

Mt Bellenden Ker Centre Peak is the wettest meteorological station in Australia; annual rainfall averages over 8000 mm, peaking at 12 461 mm in 2000 (Bureau of Meteorology 2000). West of the Babinda–Tully area, coastal cloud and rainfall influence extends much further inland, but drops to less than 1300 mm per annum west of the Atherton Tableland (Adam 1994). The approximate position of the 1250 mm rainfall isohyet is indicated on Figure 1.

Tropical cyclones are a signficant feature of the region's climate and these are recognised as being a major factor in shaping the structural and floristic differentiation of the vegetation, particularly in the coastal lowlands (Adam 1994).

Vegetation

The vegetation of the humid tropics (lat. 15–19°S, long. 145–146°30'E) (approximating the Wet Tropics bioregion) was described by Tracey (1982), based on Webb (1959, 1968, 1978) and Tracey and Webb (1975) for rainforests, and Specht (1970) for other vegetation communities. Vegetation descriptions are currently under review (Stanton & Stanton 2000, 2001a, 2001b). Thirteen rainforest structural types (Webb 1968) are recognised within the Wet Tropics bioregion (Tracey 1982).

The Wet Tropics encompasses the most diverse and the largest contiguous area of tropical rainforest in Australia. Notophyll vine forest is the major vegetation type on granite uplands across the region, whereas simple microphyll vine-fern forest/thicket predominates on cloudy wet uplands and highlands (Tracey 1982). Rocky granite outcrops on drier areas in lowlands and foothills support deciduous microphyll vine thicket. The best-developed rainforest (complex mesophyll vine forest) that generally occurs in the foothills of the highest mountains and on basaltic soils in upland areas of the Atherton Tableland, has largely been lost by clearing for grazing and agriculture. The few areas of mesophyll rainforest which do remain, including those on cloudy uplands, are mostly preserved in National Parks e.g Mossman Gorge, Daintree, Wooroonooran, Crater Lakes, Tully Gorge, Russell River, Thornton Peak. These areas, and the forest around Cape Tribulation, are extremely rich in bryophytes.

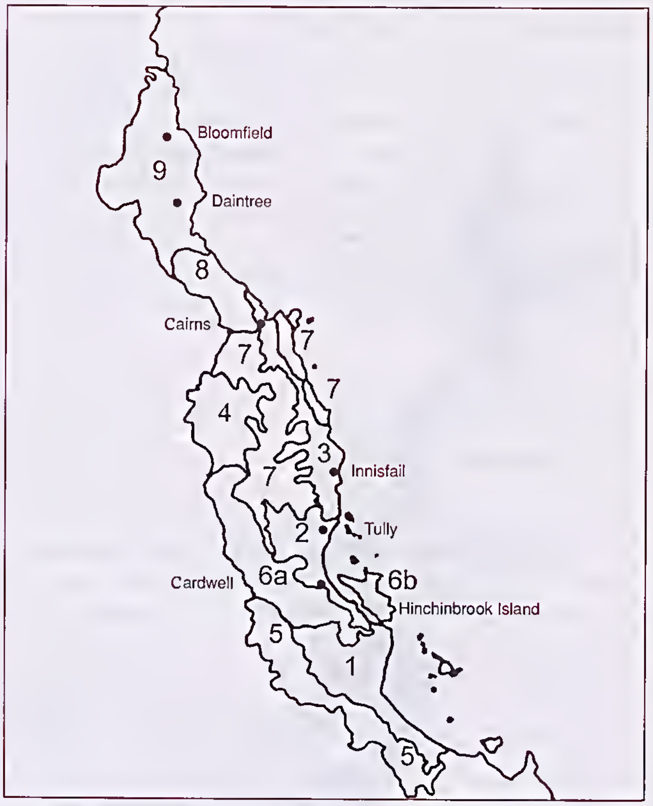
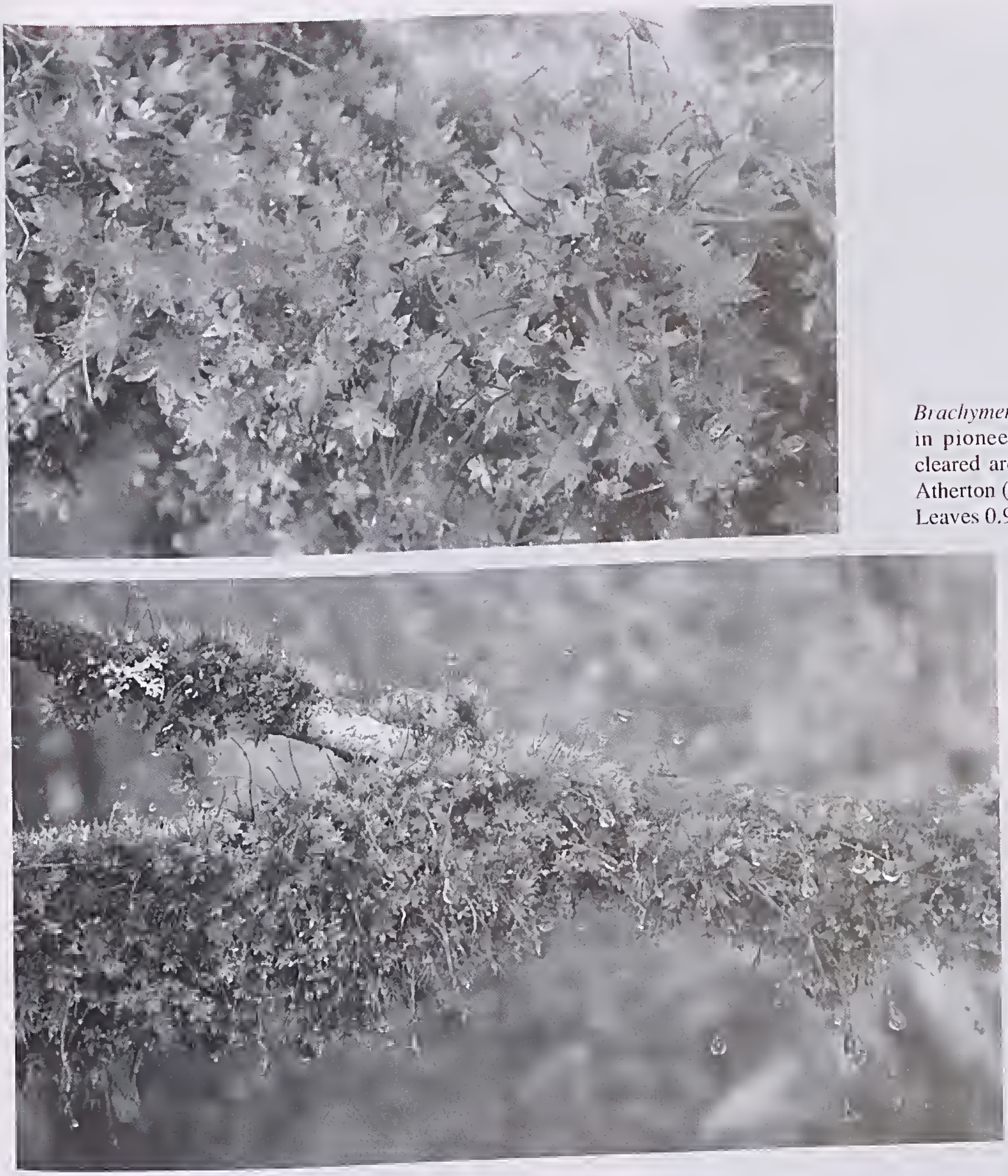


Fig. 3. Provinces of the Wet Tropics bioregion (redrawn from Satler and Williams 1999) showing approximate boundaries. Numbers correspond to the list of provinces in Appendix 1.

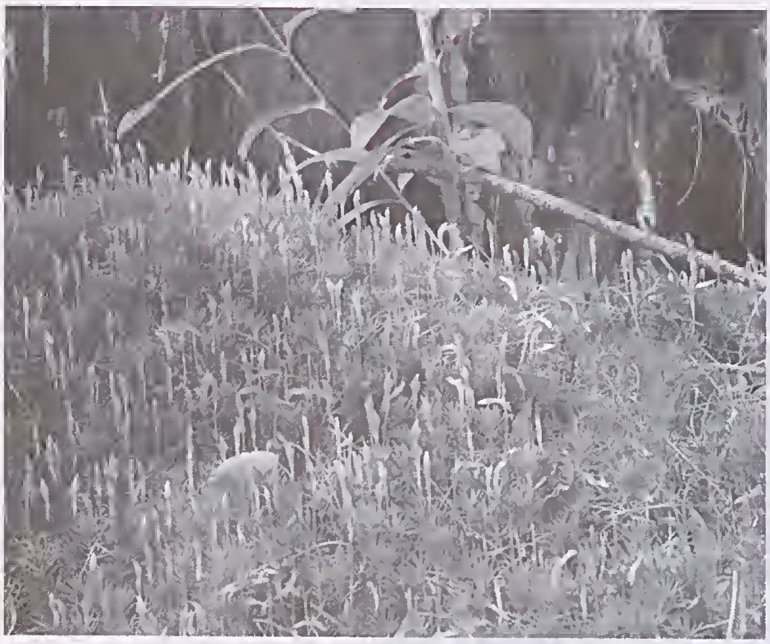
Key: 1 = Herbert, 2 = Tully, 3 = Innisfail, 4 = Atherton, 5 = Paluma–Seaview, 6a = Cardwell and Kirrama ranges, 6b = Hinchinbrook Island, 7 = Bellenden Ker-Lamb Range, 8 = Macalister, 9 = Daintree–Bloomfield.

Pockets of wet sclerophyll forests (the tall open-forest of Specht 1970) and eucalypt woodlands occur in the drier areas (1500–2000 mm per annum rainfall) and on western fringes of the Atherton and Windsor Tablelands (Tracey & Webb 1975, Tracey 1982, Kitching 1987). Plant species diversity is particularly high. Vascular plant species in the Wet Tropics number 4 500, of which approximately 3 000 are recorded from the Wet Tropics World Heritage Area (WTMA 2002).

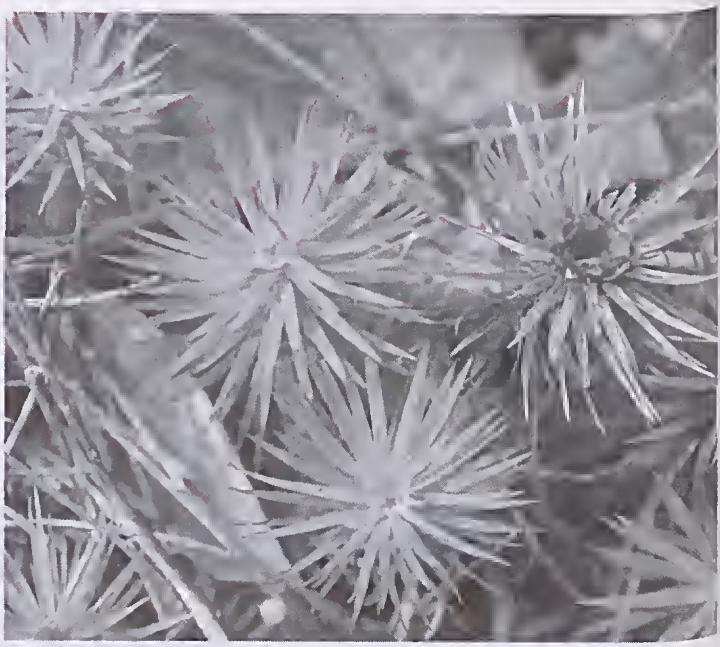


Brachymenium nepalense, epiphytic in pioneer rainforest at edge of cleared area, Longlands Gap, near Atherton (Province 4).
Leaves 0.9–1.6 × 2.4–4.8 mm.

North Johnstone River flowing through mesophyll vine forest near Malanda, Atherton Tableland (Province 4).

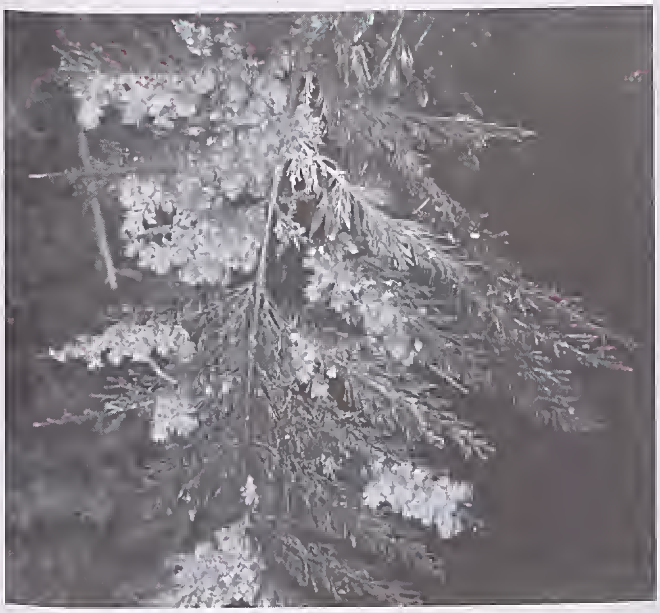


Dawsonia polytrichoides growing on tree stump in wet sclerophyll forest dominated by *Syncarpia glomulifera*, Paluma Range, near Ingham (Province 5). Leaves linear, 6–10 mm long.



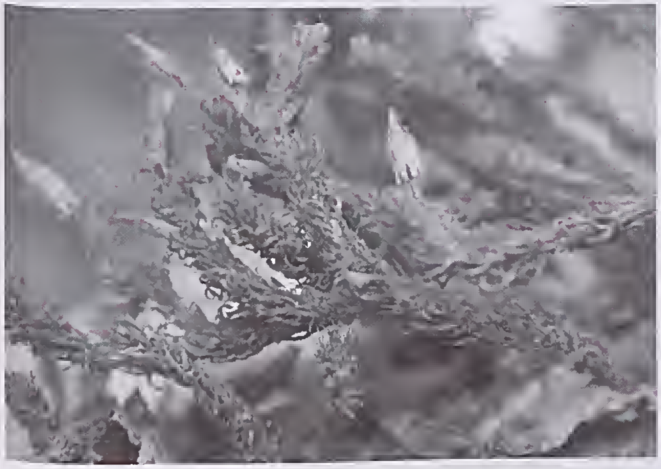
Dawsonia polytrichoides, Paluma Range, near Ingham (Province 5). Male plants; leaves linear, 6–10 mm long.

Birthday Creek, simple notophyll vine forest, alt. 800 m, Paluma Range, near Ingham (Province 5).

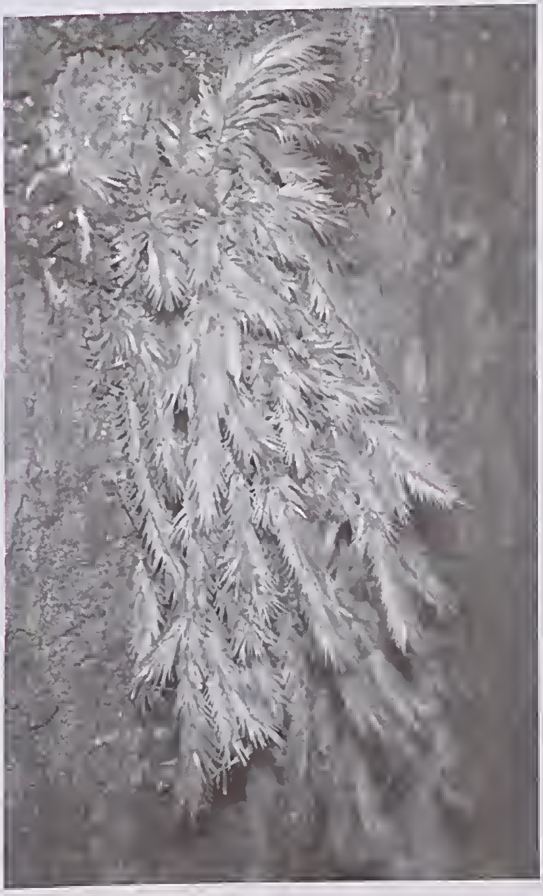


Distichophyllum mittenii growing on filmy fern (*Cephalomanes brassii*) adjacent to creek in simple notophyll vine forest, Paluma Range, near Ingham (Province 5). Leaves 2.0–2.8 × 1.0–1.2 mm.

Epiphytes at Wallaman Falls, near Ingham, Girringun National Park (previously known as Lumholtz National Park) (Province 5).

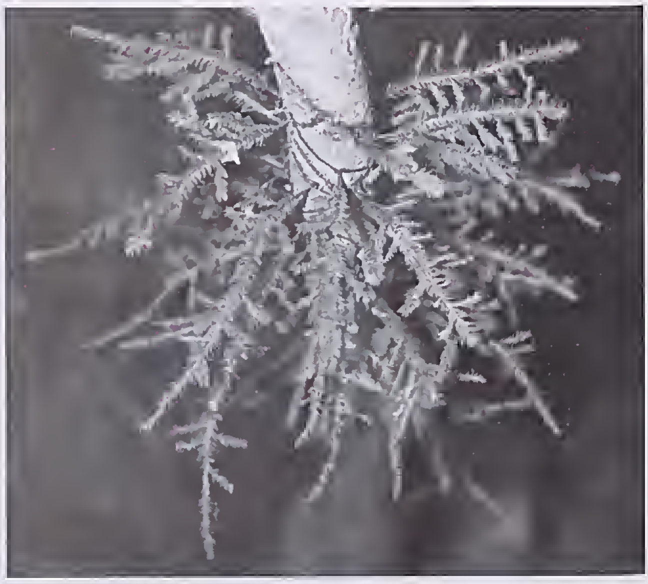


Macromitrium involutifolium, epiphytic on *Alphitonia petrei*, Paluma village, near Ingham (Province 5).



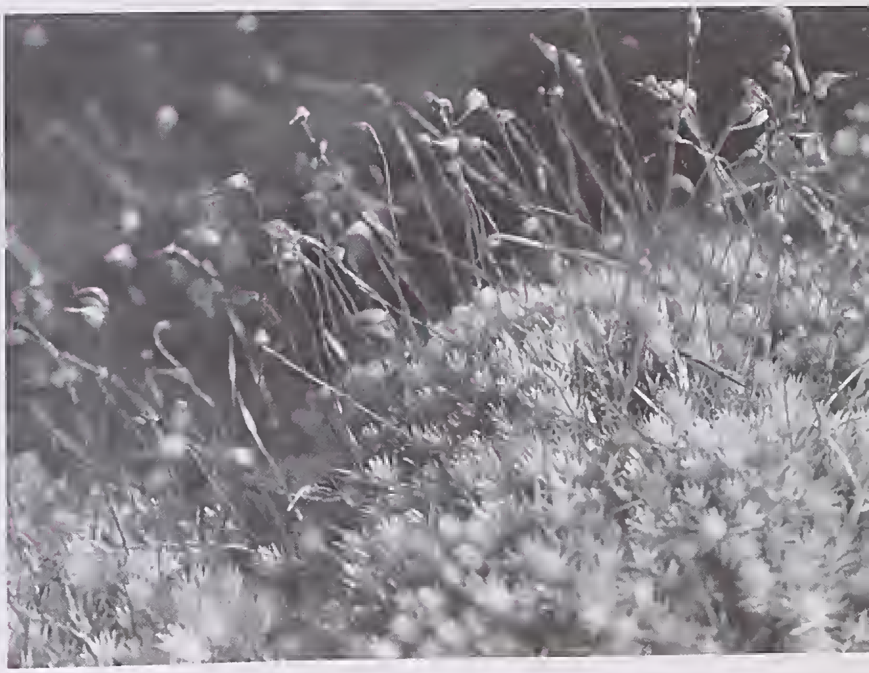
Leucobryum candidum, an epiphyte in simple notophyll vine forest, Paluma Range. Shoots 1–5 cm long.

Surrounded by eucalypt vegetation, Wallaman Falls in Girringun National Park is the longest single-drop waterfall in Australia, falling 305 m to a large pool (Province 5).

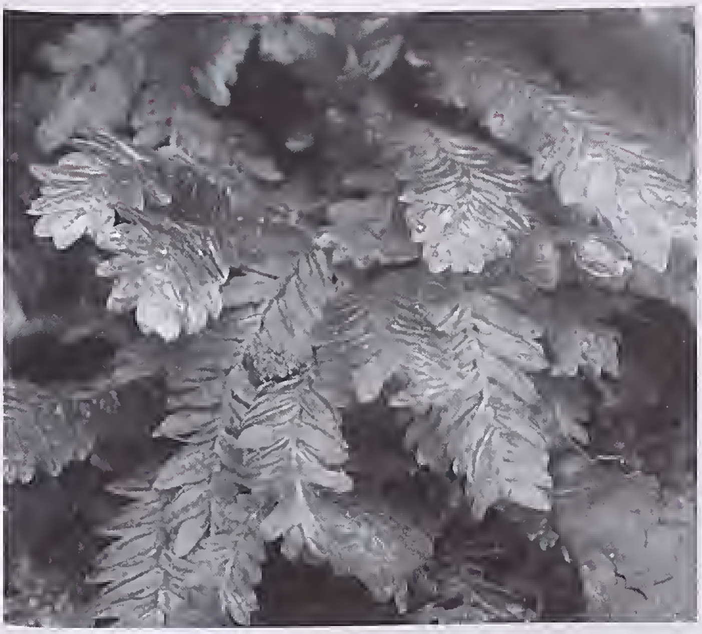


Lopidium struthiopteris growing on a sapling in simple notophyll vine forest, alt. 900 m, Paluma Range, near Ingham.

Curran Creek, Kirrama Range, near Cardwell, flowing through simple notophyll vine forest, alt. 650 m. (Province 6a).



Leucobryum aduncum, Kirrama Range, near Cardwell. Leaves 2–4 mm long.

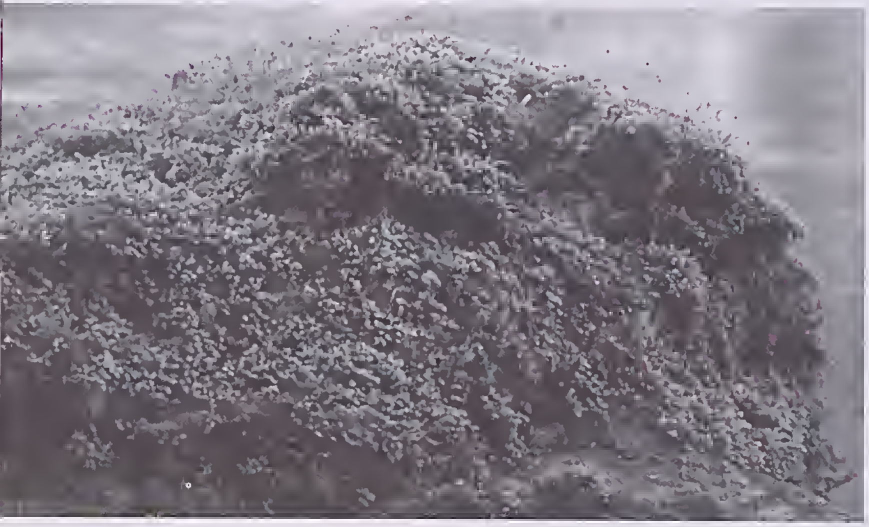


Mesochaete taxiforme growing adjacent to creek, alt. 650 m, Kirrama Range, near Cardwell. (Province 6a)
Leaves 3.4–6.0 × 1.5–2.7 mm.

Hinehinbrook Island from the mainland. (Province 6b).

Creek on the summit of Mt Bellenden Ker, in Wooroonooran National Park, near Babinda, alt. 1550 m. (Province 7).

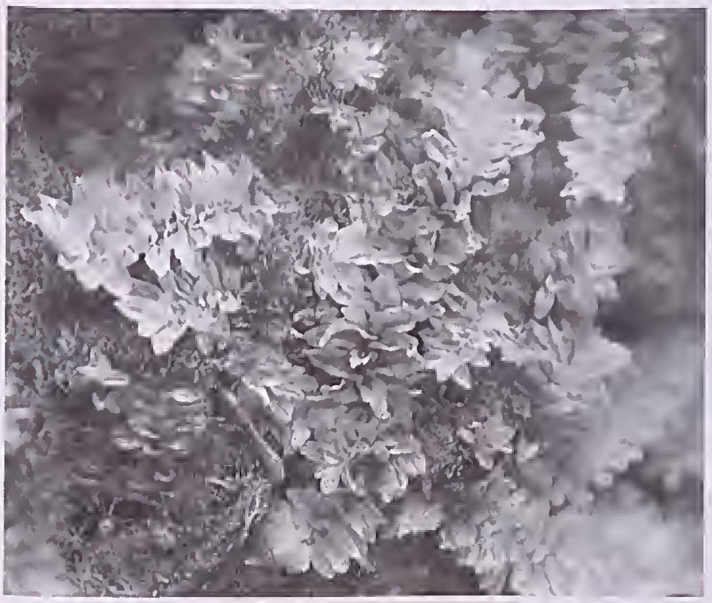
Dracophyllum sayeri (Epacridaceae) understory in simple microphyll stunted vine-fern thicket dominated by *Leptospermum wooroonooran*, on summit of Mt Bellenden Ker, near Babinda. (Province 7).



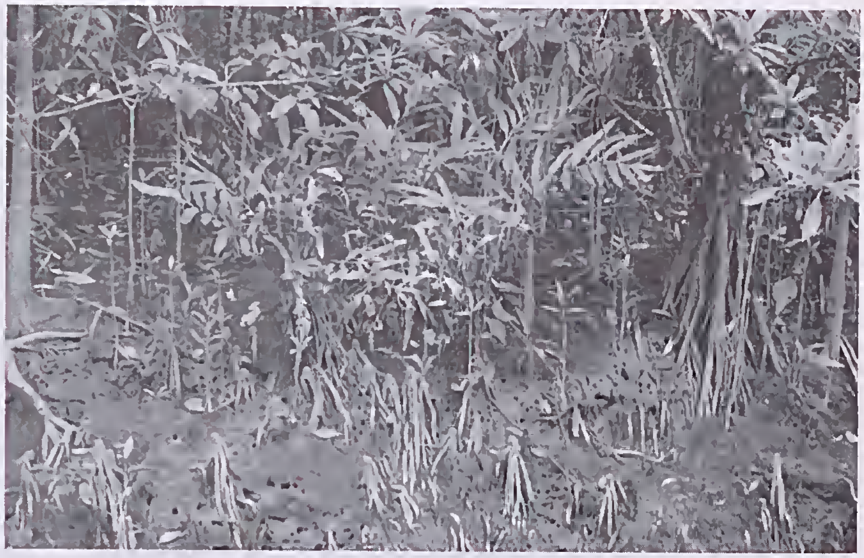
Ectropothecium zollingeri and *Fissidens crispulus* growing on rock, upper Mulgrave River, west of Mt Bartle Frere. (Province 7).

Mossy rocks and *Helmhotzia* sp. (Philidraceae), alt. 1550 m, summit of Mt Bellenden Ker, near Babinda. (Province 7).

Epiphytes at Tchupalla Falls, Wooroonooran National Park, near Innisfail. (Province 7).



Powellia involutifolia. (Province 7).
Leaves 1.5–2 mm × 0.7–1 mm.



Taxithelium merrillii carpeting mangrove mud, Russell River estuary. (Province 7).

Upper Mulgrave River flowing through mesophyll vine forest. (Province 7).

Tchupalla Falls surrounded by mesophyll vine forest, Wooroonooran National Park, near Innisfail. (Province 7).

Aims

This study was undertaken to provide an up to date checklist of the mosses of the Wet Tropics bioregion and to determine the distribution of species within the individual provinces of the region. In addition, the distribution of each species listed was compared with its phytogeographical affinities in areas close to Australia such as SE Asia (particularly Malesia, Papua New Guinea), New Zealand, New Caledonia, Norfolk Island etc. A comprehensive listing of published literature relevant to tropical Australian mosses was compiled.

Methods

This present study looks at Wet Tropics mosses in detail, including an update of species taxonomy incorporating data from revisions, new species records, and reports of additional species not previously recorded from the region. The data presented here have been obtained from literature, early collections in Herbaria including BRI, CANB (includes CBG), NSW, as well as the more recent collections made by I.G. Stone (MELU now at MEL), H. Streimann (CANB), D.H. Vitt (ALTA & NSW), H.P. Ramsay (NSW), W.B. Schofield (UBC & NSW), J.R. Spence (NSW), and others made as part of field studies during revisions undertaken for the Flora of Australia (Bryophytes). In addition, some collections made in the 1960s and 1970s e.g. those of B.O. van Zanten (GRO, NSW made in 1968), W.A. Weber (CO made in 1968) and D.H. Norris (HSC made in 1970s) have also provided useful information.

The moss checklist (Appendix 1) contains names in current use. The updated *Catalogue of Australian Mosses* (Streimann & Klazenga 2002) has been particularly useful for checking synonyms and for tracing literature. The *Catalogue* also includes important information on the distribution of the various species in Australian States other than Queensland for comparison and is not repeated here. The checklist (Appendix 1) includes data on location of species within provinces of the Wet Tropics bioregion in Australia, indicates endemics (WT) within the bioregion and those more widespread in Australia (AU), and contains distribution relationships and affinities to areas adjacent to Australia.

During the last thirty years many new species have been described from north-east Queensland and additional species recorded as a result of intensive collecting and revisions. Publications include Allen 1981, 1987; Ando 1972, 1977; Buck 1979, 1980, 1982, 1990; Buck & Crum 1978; Buck & Tan 1989; Catcheside & Frahm 1985; Catcheside & Stone 1988; Crum 1971, 1986, 1991; During 1977; Ellis 1985,1991; Enroth 1991, 1995, 1996; Frahm 1987a,b, 1988, 1990, 1991, 1992, 1993, 1994; Hedenäs 2002; Hyvönen 1989a; Ireland 1992; Isoviita 1986; Klazenga 2003; Koponen 1980, 1982, 1988, 1990; Kruijer 2002; Lai 1992; Lewinsky 1984, 1990; Miller & Manuel 1982; Mohamed 1979; Norris & Robinson 1979; Nowak 1980; Ochi 1970, 1973, 1980, 1982; Ochyra 1986; Ramsay et al. 2002a,b, 2004; Reese1989, 1992; Reese & Stone 1987, 1995; Salazar Allen 1993; Schultze-Motel 1970; Shaw 1985; Spence 1996, 2004; Spence & Ramsay 1996, 2002, 2005 (in press, Flora of Australia for Bryaceae); Stone 1975–1997 [see reference list]; Stone & Catcheside 1993; Stone & Scott 1973; Streimann 1991a,b,c, 1993, 1997, 1999, 2000a, 2001; Syed 1973; Tan et al.1996, 1998; Tangney 1996,1997; Touw 1971, 2001a,b; Touw & Falter-van den Haak 1989; Vitt 1984, 1989; Vitt & Ramsay 1985a,b.

Additional literature of use includes Buck et al. (2002), Crosby et al. (1992), Crosby & Magill (1978), Ramsay (1987), Ramsay and Schofield (1987), Ramsay et al. (1987), and Ramsay & Seur (1994).

Results

Moss Diversity

Of the 1074 accepted species of mosses in Australia, 527 are found in Queensland (Streimann & Klazenga 2002). In the Wet Tropics bioregion the present estimate of diversity is about 408 taxa (398 species, 2 subspecies, and 8 varieties) in 159 genera and 62 families. Data presented here have increased the previous estimate (Ramsay et al. 1987) of the number of species by 83 and added 20 additional families and 29 genera. The checklist (Appendix 1) includes 21 new records for the Wet Tropics and 8 new species for Australia. Lists of genera and their families, and families and their genera are presented in Appendices 2 and 3.

Families with the highest species richness in the area include Bryaceae, Calymperaceae, Dicranaceae (Table 1).

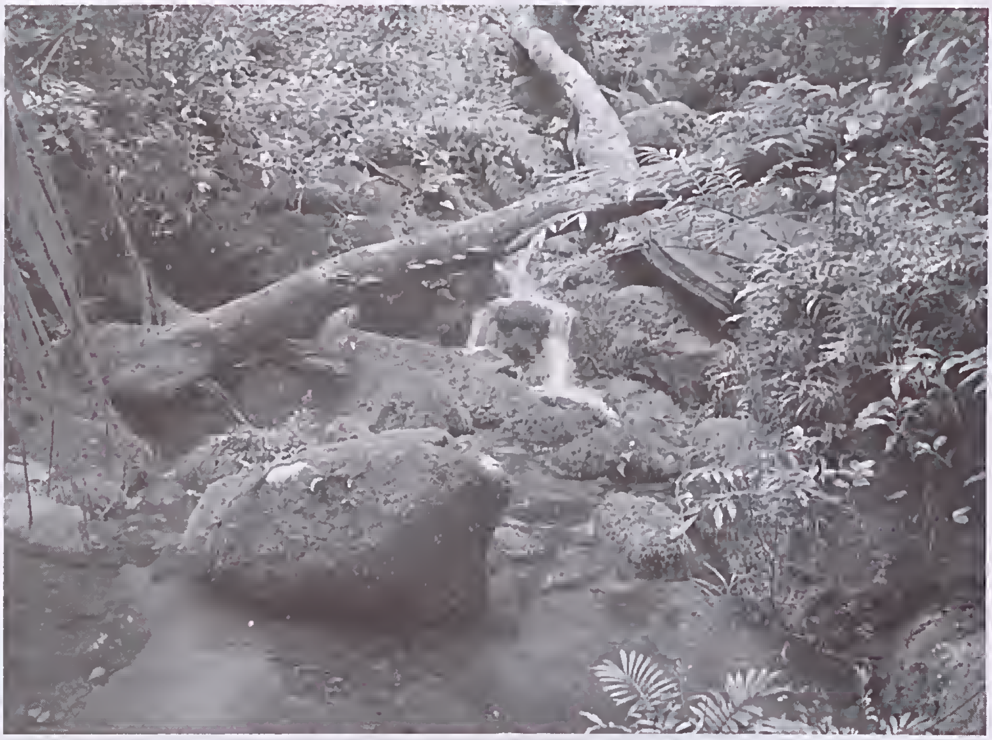
Table 1: Families of mosses with the highest species richness in the Wet Tropics.

Family	Number of genera	Number of species	
Bryaceae	5	23	
Calymperaceae	7	47	(incl. 2 varieties)
Dicranaceae	7	29	
Meteoriaceae (incl. *Papillaria*)	8	13	
Sematophyllaceae	16	32	

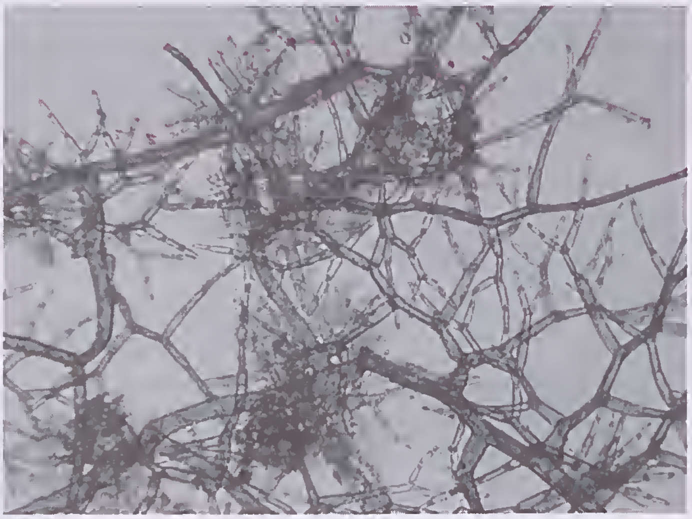
A few genera have many species in the area e.g *Fissidens*, *Macromitrium*, *Syrrhopodon* (Table 2), but many genera (see Appendix 1) are represented by only one to three species.

Table 2: Genera of mosses with the largest species representation in the Wet Tropics

Genus	Number of species	
Fissidens	35	(incl. 2 varieties)
Macromitrium	17	(incl. 2 subspecies)
Syrrhopodon	16	(incl. 2 varieties)
Calymperes	15	
Campylopus	12	
Mitthyridium	9	
Leucobryum	8	(incl. 1 variety)



Creek at Mt Lewis (Province 9), complex notophyll vine forest, alt. 800 m.



Ephemeropsis tjibodensis, an epiphyllous moss, under high power (× 400). (Province 9).

Discussion

Distribution of mosses in the Wet Tropics

Topography and rainfall patterns combine in the region to support a variety of vegetation communities, including mangroves, woodlands and rainforests of different structural types (Tracey 1982) which provide specialised habitats for bryophytes.

Mangrove communities: Mangroves have a disjunct occurrence along the east coast in intertidal areas from Torres Strait to Victoria but reach their maximum diversity in northern Australia (Specht & Specht 1999). Mosses are not common in mangroves but a few terrestrial and epiphytic species have adapted to this habitat. There are no studies of bryophytes, which include mosses, for the mangrove systems of north-east Queensland but Windolf (1989) made a study of bryophytes in an area in south-east Queensland. He recorded three epiphytic mosses and 15 leafy liverworts. Of the mosses, only *Calymperes* was recorded on mangroves, the other two species being on trees at the edges of the mangrove community. A study in Thailand by Thaithong (1984) recorded five moss species (including two species of *Calymperes*) and 21 leafy liverworts. It is clear that mosses are rare in such communities.

One notable exception is *Taxithelium merrillii*, a terrestrial species which is found as extensive mats on mud and exposed mangrove roots, particularly in mangroves that have a high freshwater input e.g. Noah Head NP, Cape Tribulation, and Russell River (Ramsay et al. 2002a). This moss is also recorded in similar communities in the Philippines (Bartram 1939, Iwatsuki & Tan 1979; Tan & Iwatsuki 1991) and South-east Asia (Tan & Iwatsuki 1993). On Hinchinbrook Island, *T. merrillii* carpets sandbars in a heavily shaded intertidal region of Mulligan's Creek, associated with *Melaleuca quinquenervia* forest (R. Lovatt pers. comm.). Unlike *T. merrillii*, species such as *Calymperes* spp., *Syrrhopodon* spp., *Macromitrium aurescens*, *Leucophanes* sp., and *Octoblepharum albidum*, epiphytic on mangrove trees, are not subject to frequent tidal inundation and are not restricted to this habitat. An ephemeral species with persistent protonema, *Archidium minutissimum* was recorded from sandy soil at the edge of mangroves south of Cooktown where it was submerged at exceptionally high tides (Stone 1985b). Three other collections in the area were not associated with a mangrove habitat. The species has not been seen since 1984 and is worth further investigation in season.

Freshwater habitats: Aquatic mosses are not abundant in streams in the region. Obligate aquatics are more common in cooler climates (Vitt & Glime 1984, Suren 1993); however, many ground-dwelling moss species may also be found growing submerged in freshwater habitats (Scott 1994). In most stream systems, variable current velocities, water levels and humidities contribute to broad environmental gradients from aquatic to terrestrial habitats. In streams at higher elevations where water temperatures are generally lower, some species of genera such as *Bryum*, *Philonotis*, *Distichophyllum*, *Hypnodendron* and *Fissidens* are common both above water and immersed, particularly in areas of low flow. The morphology of certain species appears to be influenced by environmental conditions e.g. fronds of *Hypnodendron vitiense* subsp. *australe* extend much further when growing submerged (A. Touw pers. comm.).

The occurrence of mosses in freshwater habitats in the Wet Tropics may be more common than previously recorded. An unpublished study on the Atherton Tableland (average elevation 700–800 m) showed there is often extensive growth of submerged mosses. In Mazlin Creek, near Atherton, the cosmopolitan moss *Leptodictyum riparium* flourished in a fast-flowing stream where nutrient levels were high. Biggs (1996) determined that bryophytes dominate in steeper headwater streams with stable substrates that promote fast-flowing, turbulent waters, often with high flow variability. However, *Taxiphyllum taxirameum* was also recorded near Atherton, growing abundantly in a permanent spring-fed pool with minimal current velocity, with a constant water temperature of around 22°C. The flow environment of stream bryophytes in the Wet Tropics warrants further attention.

More intensive surveys are clearly needed. The Wet Tropics endemic *Touwia laticostata* is known from only one stream (altitude 300 m) on Mt Bellenden Ker (Ochyra 1986). The aquatic moss *Platyhypnidium muelleri* is also reported from that area (Scott 1994), as is *Platyhypnidium austrinum*. In his overview of the Brachytheciaceae in Australia, Hedenäs (2002) concluded that Australian specimens of *P. muelleri* are more likely to be *P. austrinum*; however, both species have been confirmed in the Wet Tropics. A recent survey (Cairns & Werren 2002, unpublished) of the upper East Mulgrave River revealed extensive submerged beds of *Ectropothecium zollingeri*, previously unrecorded in the Mulgrave catchment, in a shaded riffle. The only record of *Sphagnum* in the area is *Sphagnum perichaetiale* from a *Melaleuca* swamp near Bramston Beach (Stone 1990c).

Terrestrial mosses: Terrestrial bryophytes act as colonisers of soils or in drier areas of south-western Queensland they form an important component of soil crusts (Eldridge et al. 2000). Bryophytes are not abundant on the earth floor of tropical rainforests, perhaps because the continual build-up of leaf litter restricts their development. Nevertheless, in wetter areas in the Wet Tropics, the soil-binding capacity of some terrestrial mosses is significant and they are able to quickly colonise surface soil of newly disturbed steep earth banks and reduce erosion. In the Wet Tropics, *Pogonatum* and *Dawsonia* colonise large areas of the more exposed road cuttings, and *Dicranella* and more rarely *Garckea*, the more protected cuttings. Many species of *Fissidens* are prominent as colonisers of shaded earth banks or forest tracks, some in coastal areas e.g. *F. crispulus*, *F. perobtusus*, and others at higher altitudes e.g. *F. dietrichiae*, *F. pallidus*. Tiny earth mosses such as *Archidium*, *Erpodium*, and *Gigaspermum* are often present but may be hard to find. The families Bryaceae (e.g. *Rosulabryum* spp., *Gemmabryum* spp.), Dicranaceae (e.g. *Dicranella*, *Campylopus*, *Dicranoloma*), Funariaceae (e.g. *Funaria hygrometrica*) and Pottiaceae (e.g. *Barbula*) (Zander 1993) include many taxa of importance in colonising bare soil or shallow soil over rock surfaces.

Epiphytic and epiphyllous mosses: The rainforest presents a range of microhabitats and substrates for bryophytes to colonise, depending on the diversity of microclimates and their individual ecological tolerances. Pócs (1982) observed the zonation of epiphytes in rainforests in Africa, both vertically and horizontally, and differentiated four broad zones on the phorophyte – basal trunk, main trunk, branches, and terminal twigs. The spatial distribution of corticolous bryophytes is therefore determined by a network of fluctuating variables e.g. light intensity, temperature, relative humidity, air currents (Smith 1982, Franks & Bergstrom 2000).

Epiphytic bryophytes contribute significantly to the diversity of tropical rainforests worldwide. In lowland forests in French Guiana, Montfort and Ek (1990) found 154 species of bryophytes, (42% were mosses), on 28 trees representing 22 species. Along an altitudinal gradient in the Columbian Andes, Wolf (1993) found that mosses comprised 36.6% of the 295 epiphytic bryophyte taxa identified.

In south-east Queensland, Franks (2000) and Franks and Bergstrom (2000) found that epiphytic bryophytes formed a significant component of microphyll fern forests. Sampling on *Nothofagus moorei* trunks was carried out from ground level to 2 m on 25 individual trees and showed that the composition and community structure altered with both height above ground level and the direction of exposure (Franks & Bergstrom 2000). Patterns of distribution were thought to reflect changes in moisture availability and degree of desiccation tolerance of the various taxa. Of forty-three bryophyte taxa, 37% were mosses. These represented a range of families and genera including Calymperaceae: *Syrrhopodon armatus*; Dicnemonaceae: *Eucamptodon muelleri;* Dicranaceae: *Dicranoloma* spp.; Hookeriaceae: *Cyathophorum bulbosum*; Hypnaceae: *Hypnum cupressiforme*; Hypopterygiaceae: *Lopidium concinnum*; Lembophyllaceae: *Lembophyllum divulsum;* Leucobryaceae: *Leucobryum candidum*; Orthotrichaceae: *Macromitrium exsertum*; Ptychomniaceae: *Hampeella pallens*; Rhizogoniaceae: *Pyrrhobryum paramattense*; Sematophyllaceae: *Wijkia extenuata*.

No such studies have yet been undertaken for the Wet Tropics, although observations indicate that the species composition of rainforest epiphytes would include some of the species recorded by Franks and Bergstrom (2000), but are also likely to include a range of taxa of tropical origin not found in the south-east forests. Examples include various genera and species in families including Calymperaceae, Sematophyllaceae, Orthotrichaceae and Meteoriaceae.

Epiphyllous mosses occur in the wetter forests and moist rainforest gullies of the Wet Tropics e.g. Mt Bellenden Ker summit, Mt Lewis. Again, no studies have been reported. Worldwide, epiphyllous mosses are uncommon compared with tiny leafy liverworts (Lejeuneaceae), and in tropical America, Africa and Asia are mostly members of the Hookeriaceae (Gradstein 1997, Bates 2000). In the Wet Tropics this does not appear to be the case, although *Distichophyllum mittenii* has been found growing on the leaves of filmy ferns (*Cephalomanes brassii*) (unpublished data). Obligate epiphyllous bryophytes tend to be minute plants, growing appressed to the leaf surface, anchored by bundles of rhizoids (Gradstein 1997). Few mosses fit this description. One notable exception is *Ephemeropsis tjibodensis*, which consists of a protonemal gametophyte and forms dense algal-like patches on the surface of leaves. Most mosses growing on leaves are facultative epiphylls (Gradstein 1997), spreading onto angiosperm leaves from adjacent twigs e.g. members of the Meteoriaceae: *Barbellopsis trichophora*, *Aerobryopsis longissima*, *Meteorium polytrichum*.

Richards (1984) noted that different types of forest structure affect levels of light and humidity, providing a range of microclimates within the forest. The bryological diversity of the Wet Tropics bioregion may be a reflection, in part, of differences between rainforest types and the variety of microhabitats they offer. However, to date, few bryologists have listed the rainforest habitat of moss collections according to these classifications (one notable exception is Reese & Stone 1995), and there have been no published analyses of bryophyte communities in relation to rainforest types.

Mosses of other vegetation communities: 'Dry' rainforest (Gillison 1987), *Casuarina* dominated riparian vegetation, and other non-sclerophyll communities have been highlighted as worthy of investigation (Streimann 1994, 2000b). Patches of these vegetation types occur throughout the Wet Tropics, particularly in areas of lower rainfall; nevertheless, an understanding of the bryophyte flora of these habitats is lacking. A survey of the moss flora of dry rainforests to the west of the Wet Tropics revealed a unique assemblage, comprising species from wetter areas and species from drier environments (Fensham & Streimann 1997). Of these habitats, Streimann (1994) commented: 'The species numbers may not be so great, nor the colonies as spectacular, but they do contain an interesting and poorly studied bryophyte flora which may be bryogeographically exciting and significant'.

Mosses with a restricted distribution

Species with restricted distributions include those limited to high mountain peaks and lowland forests. In addition, many Southeast Asian mosses (Appendix 1) are at the limits of their range in the Wet Tropics (Reese & Stone 1995) e.g. *Calymperes porrectum* recorded only from Cape Tribulation, *Macromitrium incurvifolium* recorded from Big Tableland south of Cooktown, Mt Lewis, and the Russell River. Others have restricted altitudinal ranges e.g. *Syrrhopodon prolifer* which has one variety, var. *prolifer*, found above 1200 m, and the other variety, var. *mossmanensis* found below 500 m (Fig. 4c). While this species is pantropical, the varieties are each represented in Queensland from a single locality, the type variety *S. prolifer* var. *prolifer* from Thornton Peak and the other *S. prolifer* var. *mossmanensis* from Mossman (Reese & Stone 1995).

Mosses restricted to high mountain peaks: Mountain peaks receive high levels of rainfall and high altitude forests ('cloud' forests) may also capture considerable amounts of water from passing clouds (Foster 2001). They therefore offer unique habitats not found elsewhere in the tropics. In tropical regions worldwide, the mass and diversity of both mosses and liverworts increases with altitude (Buck & Thiers 1989). The Wet Tropics is no exception, and bryophytes are particularly abundant in the cloud belt (1200–1600 m) in simple microphyll vine-fern thicket (Webb 1968). Epiphytic mosses are widespread, but some are known only from one or two sites e.g. *Calyptrochaeta rotundifolia*, *Clastobryum dimorphum*, *Daltonia contorta*, *Macromitrium funiforme*, *Macromitrium dielsii* (Mt Bellenden Ker and/or Mt Bartle Frere), *Meiothecielia papillosa* (Mt Spec near Townsville). Some mosses which are common in lower altitudes in southern Australia and are also in New Zealand e.g. *Calyptrochaeta apiculata*, *Cyathophorum bulbosum*, *Daltonia splachnoides*, *Dicranoloma menziesii* and *Warburgiella leucocytus*, are present only on the highest peaks in the Wet Tropics, where cooler temperatures prevail and there is constant mist and cloud. Streimann (2000b) nominated isolated peaks and ranges in the Wet Tropics as 'hot spots' both for endemics, and species with affinities to Southeast Asia and Malesia (see Tan & Iwatsuki 1999).

Contemporary climate change has been nominated by Williams et al. (2003) as a significant threat to the long-term preservation of the biota in the tropical rainforests of the Wet Tropics. Complex notophyll vine forests, simple notophyll and simple microphyll forests and thickets in the wet uplands and highlands have been identified as particularly sensitive to even moderate increases in temperature (Hilbert et al. 2001). On the highest mountains, the cloud base is expected to increase in altitude and consequently reduce mist (Foster 2001, Hilbert et al. 2001). Extinction risks for bryophytes endemic to these unique habitats are high.

Mosses of the lowland coastal belt: Included here, apart from terrestrial mosses, are many epiphytic species in high rainfall areas at lower altitudes: e.g. *Chaetomitrium tahitense*, *Leucophanes* spp., *Octoblepharum albidum*, *Leucobryum* spp. Most taxa in the family Calymperaceae (e.g. *Calymperes*, *Mitthyridium* and *Syrrhopodon*) are well represented at lower altitudes, generally below 500 m (Fig. 4 A–C) (Reese & Stone 1995) with very few restricted to higher altitudes. The family Sematophyllaceae includes species such as *Acanthorrhyncium papillatum*, *Radulina hamata*, *Taxithelium instratum*, *T. nepalense* and *Trismegistia lancifolia*, that are well represented in lowland regions such as Cape Tribulation, Mossman Gorge, Daintree National Park. (Ramsay et al. 2002a).

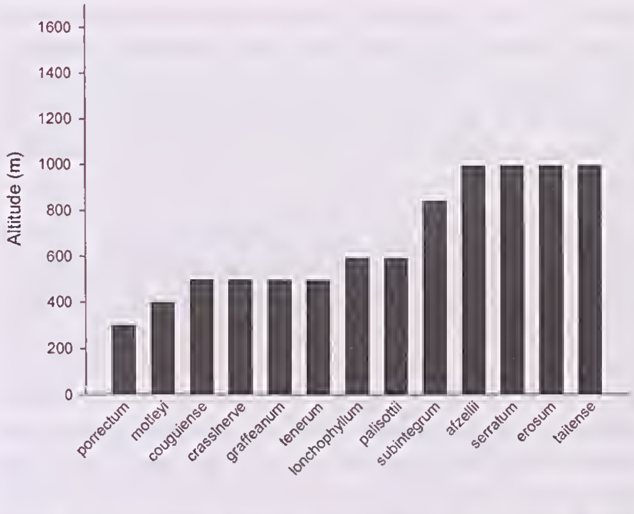


Fig. 4A. Distribution of *Calymperes* species by altitude (Reese and Stone 1995).

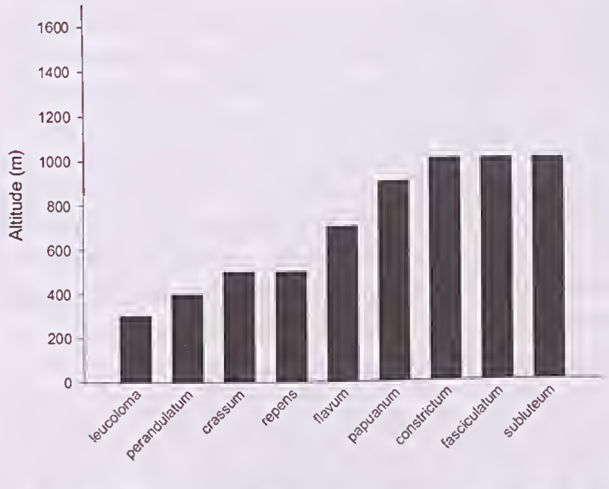


Fig. 4B. Distribution of *Mitthyridium* species by altitude (Reese and Stone 1995).

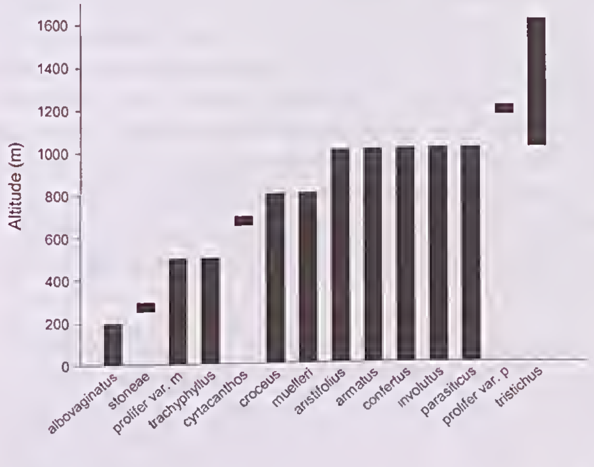


Fig. 4C. Distribution of *Syrrhopodon* species by altitude (Reese and Stone 1995).

Bryophytes are generally thought to be few in lowland tropical forests compared with forests at higher altitudes. Streimann (1994) suggested that bryophyte diversity in these habitats is, in fact, much greater than it appears; many species are restricted to tree canopies and are not easily accessible.

Species widely distributed throughout the area: Some species have wide-ranging geographic distributions throughout the area, at various altitudes. Species such as *Bryobrothera crenulata* and *Callicostella papillata* var. *papillata* are found from Mt Finnigan in the north, to Eungella south of the area (Streimann 2001). *Hookeriopsis utacamundiana* ranges from Mt Bellenden Ker and Mt Bartle Frere to Eungella, some 800 km south. Others that are more widely dispersed in the tropics e.g. *Calymperes erosum*, distributed across northern Australia (QLD, WA & NT), occur as far north as Cape York and extend south to Proserpine (Reese & Stone 1995).

Phytogeographical affinities of mosses in the Wet Tropics

Affinities of the bryoflora of this tropical part of Australia range from endemic species, to species of Gondwanan origin, present primarily in Australia and New Zealand but also in South America and southern Africa. Gondwanan taxa occur frequently in ancient rainforests or montane ecosystems. Many have palaeotropical affinities with species in Malesia and Southeast Asia. Others have relationships to the flora of New Caledonia and/or Oceania and the Pacific. Some cosmopolitan species are also represented e.g. *Funaria hygrometrica*.

Species reported as endemic to area

The Wet Tropics bioregion is well known for the ancient nature and high degree of endemism of vascular plants (Keto & Scott 1986), and has been nominated as a significant centre for endemism (Boden & Given 1995, Crisp et al. 2001). Surprisingly, present studies have found that the number of moss species endemic to the Wet Tropics bioregion is much lower than expected, representing less than 7% of the species present (Appendix 1 as WT). This disparity can perhaps be explained by the comparative ease of dispersal of bryophytes by spores or asexual propagules (Laaka-Lindberg 2003). Similar rates of endemism have been estimated for tropical regions elsewhere e.g. Galapagos Islands 10%, Cuba 12%. Mt Kilimanjaro 6% (Frahm 2003). Taxa formerly considered to be endemic may now be in synonymy under another name or, particularly in the case of small earth mosses, may yet be found in other countries. Others may possibly be synonymous with Southeast Asian mosses at the extremity of their range.

Endemic species of *Fissidens* are associated with moist lowland areas. Isolated mountain peaks are particularly important habitats for some taxa e.g. Mt Finnigan (*Calyptrochaeta brassii*), Mt Bellenden Ker, Mt Bartle Frere and Mt Lewis (*Clastobrum dimorphum*) (Streimann 2000b). Endemic species come from a wide range of families and genera e.g. Brachytheciaceae: *Rhynchostegium nanopennatum* Buxbaumiaceae: *Buxbaumia thorsborneae;* Fissidentaceae: *Fissidens flabellulus*. var. *eachamensis*, *F. gymnocarpus*, *F. henryae*; Hypnodendraceae: *Hypnodendron comatulum*; Neckeraceae: *Touwia laticostata*; Orthotrichaceae: *Macromitrium dielsii*, *M. fusiforme*.

More widespread Australian endemics in the area

Many Australian endemic species (AU in Appendix 1) that are found in the Wet Tropics have a pattern of distribution along the east divide, often in pockets of remnant forest e.g species belonging to *Dicranoloma*, *Eucamptodon*, *Fissidens*, *Macromitrium*, *Papillaria*, *Schlotheimia*. Although this study has added about 83 additional taxa to the total previously recorded from the area, the numbers of Australian endemic species (AU), including those that occur exclusively in the Wet Tropics (WT), has been reduced in this study compared to the earlier estimates made by Ramsay et al. (1987), to about 25% species. The genus with the largest numbers of endemic species is *Fissidens* 14 spp. (including 7 in WT), with *Macromitrium* 12 spp. (2 in WT), *Archidium* 6 spp. (1 in WT); and 12 genera are each represented by a single endemic species.

Moss species occurring across northern tropical Australia

A number of species from the Wet Tropics bioregion also occur throughout northern tropical Australia including north Queensland, the Northern Territory and/or northern Western Australia (Table 3). Little is known about the wetter parts of the Northern Territory, particularly the moist monsoon vegetation of Arnhemland, an area highlighted by Streimann (2000b) as worthy of further exploration. Families well represented across the northern tropics include Archidiaceae, Bryaceae, Calymperaceae, Fissidentaceae and Sematophyllaceae. Many of these are also distributed in the palaeotropical regions of Southeast Asia, particularly Malesia. In the Calymperaceae for example, while 42 taxa in three genera occur in Australia (Reese & Stone 1995), the majority are present in the warm humid tropics of the Northern Territory and north-east Queensland. Across this region, *Syrrhopodon* has 18 taxa and *Calymperes* 14, while two species (*C. tenerum* and *C. erosum*) also occur in northern Western Australia. The other genus in the Calymperaceae, *Mitthyridium*, occurs as a single species, *M. flavum*, in the Northern Territory, with the nine Australian representatives all in the Wet Tropics. In the Sematophyllaceae, species such as *Taxithelium* spp. and *Radulina hamata* are present in north-east Queensland and the Northern Territory, while *Papillidiopsis ramulina* has been recorded from north west Western Australia and the Northern Territory but not Queensland (Catcheside & Stone 1988, Stoneburner et al. 1993, Ramsay et al. 2002b, 2004).

Table 3. Representative moss species occurring across northern tropical Australia

Archidium ohioense
Archidium rothii
Brachymenium indicum
Bryum argenteum
Calymperes afzelii
Calymperes erosum
Calymperes graeffeanum
Calymperes motleyi
Calymperes porrectum
Calymperes tenerum
Campylopus laxitextus
Ecremidium minutum
Erpodium coronatum
 var. *australiense*
Fissidens ceylonensis
Fissidens curvatus
Fissidens gymnocarpus
Fissidens holstii
Fissidens perobtusus
Garckea flexuosa
Gemmabryum apiculatum
Gemmabryum indicum
Hyophila involuta
Leucobryum aduncum
Leucobryum aduncum
 var. *scalare*
Leucobryum chlorophyllosum
Leucophanes glaucum
Mitthyridium flavum
Octoblepharum albidum
Pelekium investe
Radulina hamata
Taxithelium instratum
Taxithelium kerianum
Taxithelium nepalense
Taxithelium planum
Taxiphyllum minutiramenum
Trachyphyllum inflexum

On the Cape York Peninsula, north of the Wet Tropics, Crisp et al. (2001) found significant floristic links between the eastern coastal strip and Trans-Fly and Port Moresby 'dry' areas in Papua New Guinea. Their recent nomination of the Iron Range-McIlraith Range region to the north of the Wet Tropics as an important centre of endemism for vascular plants suggests that this area should be further investigated by bryologists. Patches of vine thicket on Cape York Pensinsula have revealed several previously unreported genera and species (Streimann 2001a); however, bryological surveys of the Cape are few, possibly due to the difficulties of access. Similarly, islands of the Torres Strait, between Australia and New Guinea, are bryologically unknown, although Streimann (2001) suggests that there is no reason why, for example, Hookeriaceae should not occur there.

Afffinities with the mosses of Southeast Asia and New Caledonia

Floristic affinities: Strong affinities exist beween rainforest angiosperms in the Wet Tropics, Malesia and New Caledonia (Morat 1986). Based on cladistic biogeographical analyses, Crisp et al. (1999) reviewed relationships between distribution patterns of angiosperm taxa. They described a northern element of the 'South Pacific track' which appeared to link New Guinea, Queensland, Northern Territory, New Caledonia and Fiji, and concluded that 'the flora of Australia is most closely related to that of its Gondwanan neighbours', noting that there are biogeographical anomalies yet to be resolved. Acknowledgement of tropical flora as 'palaeo-autochthonous, derived from Gondwanan stock' (Webb et al. 1986) is now widely accepted (Specht & Specht 1999). Walker (1990) agreed that the specific interrelationships of some groups of plants [and animals] in rainforests imply a long evolutionary association i.e. the occurrence of species together is more than just chance and is indicative of the maintenance of rainforest assemblages through time (Webb et al. 1986). Re-assembly of tropical forests by expansion from refugia (Webb & Tracey 1981), as has occurred as a result of Quaternary climatic oscillations (Williams et al. 1993), would be a mechanism for increased diversity through random processes. Extrapolation of these conclusions to include all plants should, however, be approached with caution; bryophytes employ significantly different dispersal mechanisms (e.g. spores, fragments, gemmae) compared with flowering plants. Tan and Pócs (2000) emphasised that a regional bryoflora is developed as a result of the complex processes of long-distance dispersal, vicariance events, extinction, and the vicissitudes of climate during the Tertiary and Quaternary.

Affinities with the mosses of Malesia and Southeast Asia

Relationships exist between Australian bryophytes and those of the Palaeotropics, particularly Papua New Guinea, the Philippines, Borneo and other parts of Southeast Asia. About 45% of the moss species in the Wet Tropics have affinities with those regions (Appendix 1). Within Malesia, the Malay Peninsula, Sumatra, and Borneo in the west, and New Guinea in the east, form cores of ever-wet climate. These border a mosaic of wet and seasonal areas (the Philippines, Sulawesi, the Moluccas, Java, and the Lesser Sunda Islands), which form a corridor connecting the seasonally dry areas of tropical Southeast Asia and Australia (Touw 1992b). The Moss Flora of Malesiana (Eddy 1988, 1990, 1996) lists many species common to both areas. By comparison affinities of Wet Tropics mosses with those of temperate rainforests of New Zealand is only 15% (Appendix 1).

Klazenga (1999) reported that the genus *Dicranoloma* shows a Malesian-Australasian-Pacific distribution extending marginally into Southeast Asia. The genus *D. braunii* is widespread in Malesia but in Australia occurs only in north-east Queensland, while *D. menziesii* occurs in Papua New Guinea and is found throughout eastern Australia, New Zealand and New Caledonia (Klazenga 2003).

Between Australia and the Lesser Sunda Islands (South Malesia), species such as *Sclerodontium pallidum* and *Thuidiopsis sparsa* are seasonal drought-tolerant plants from more or less exposed habitats (Touw 1992, 2001a). These distribution patterns might be explained by exchange of biota between Malesia and Australasia long before the collision of Gondwana and Laurasia; however, Touw (1992) considered these patterns to be the result of post-glacial establishment during the Miocene. Similarly, *Mittenia plumula*, reported from Mt Spee in the southern Wet Tropics bioregion but more common in eastern Australia, Tasmania, Papua New Guinea and New Zealand, also occurs in Western Malesia, probably as the result of post-glacial colonisation (Tan 1998). Nevertheless, the Australian element is far smaller in the Lesser Sunda Islands than one would expect from their proximity (Touw 1992). The family Thuidiaceae includes species such as *Pelekium gratum* and *P. synoicum* with affinities to Southeast Asia. One species, *P. velatum*, so far reported only from central coastal Queensland by one record (Touw 2001b) but common in Malesia, could well be found in the Wet Tropics.

The same is true of affinities between New Guinea and Australia (Piipo and Koponen 2003). Montane forests in New Guinea and South Malesia include only 12 species of mosses with Australian affinity (Ramsay et al. 1986). In the genus *Macromitrium*, well represented in both New Guinea (29 spp.) (Vitt et al. 1995) and Australia (22 spp.) Vitt and Ramsay 1985a, b), only two species are common to both areas. Examples of species with restricted distribution between north-east Australia and New Guinea include *Acroporium lamprophyllum* var. *percaudatum*, *Gemmabryum australe*, *Groutiella tomentosa*, *Macromitrium incurvifolium*, *Orthomnium elimbatum*, *Pogonatum neesii*, *Sorapilla papuana* (Norris and Koponen 1989a, b; van Zanten and Pócs 1981, Vitt et al. 1995, Tan et al. 1996, Ramsay et al. 1995 Spence & Ramsay 2005, Flora of Australia vol 51 in press). In an analysis of the biogeography of the Bryaceae (subfamily Bryoideae) and its relatives in tropical regions of north-east Queensland, Spence and Ramsay (1996) found that the strongest affinities are with Malesia (including New Guinea). The family Sematophyllaceae has strong affinities with Malesia with many species of the genera found in Australia such as *Acroporium*, *Acanthorrhynchium*, *Clastobryum*, *Meiothecium*, *Taxithelium*, *Trichosteleum*, *Trismegistia*, *Warburgiella*, and *Radulina* having species common to these areas (Ramsay & Schofield 1987; Ramsay et al. 2002a, b, 2004; Tan et al. 1992).

Gondwanan distributions in temperate rainforest zones of Australasia and South America, as well as in the tropical montane forests of Malesia and Sri Lanka, suggest fragmentation of a continuous area forming a mosaic of wetter and drier environments. Gondwanan families such as Dawsoniaceae (van Zanten 1973), Hypnodendraceae (Touw 1971), Racopilaceae (van Zanten & Pócs 1981, van Zanten & Hofman 1995) and Leptostomataceae (Crum 1989) also occur in New Guinea and the western Pacific. Genera such as *Campylopus* have distribution patterns that include Africa (Frahm 1992) as well as Southeast Asia. Distribution of the genus *Papillaria* (Meteoriaceae) includes both Malesia/Southeast Asia and the Pacific, with greatest diversity in New Caledonia (Streimann 1992). In the Daltoniaceae [Hookeriaceae], *Calyptrochaeta apiculata* has a disjunct distribution, occurring in the Wet Tropics on Mt Bellenden Ker and in southern Australia, but also reported from Chile, Argentina, the Falkland Islands, and New Zealand (Streimann 2000a).

Distunctive patterns of distribution may be difficult to resolve. In the Neckeraceae, *Caduciella marei*, known in Australia from one specimen collected near the Daintree River in 1882 (Enroth 1991), has also been reported from Tanzania, the Comoro Islands, India (Assam), SW China, Indochina, Malesia and Oceania. Tan (1998) considered this widespread distribution to represent either fragmented parts of a former continuous Gondwanan range or the result of chance dispersal between extant populations on three continents.

Commenting on disjunctive patterns of bryophyte distribution between South Malesia/Philippines and Australasia/Oceania, Tan (1998) attributed the presence of Gondwanan taxa in Malesia e.g. *Bescherellia elegantissima* and *Dawsonia superba* (also present in the Wet Tropics), to their arrival following the collision of SE Asia and the Australian margin in the mid-Miocene; reciprocal invasions into northern Australia could also have occurred during this period. Affinities of moss species across tropical Australia and Malesia/Southeast Asia demonstrate that there are strong phytogeographical relationships between the palaeotropical areas and north-east Queensland. This may be at the family, generic or species level. Taxa come from a wide range of families including Archidiaceae, Bryaceae, Calymperaceae, Daltoniaceae, Fissidentaceae, Meteoriaceae, Orthotrichaceae, Thuidiaceae, and Sematophyllaceae.

Species in the Wet Tropics with affinities to the mosses in Southeast Asia (particularly Malesia) are indicated in Appendix 1. Publications pertaining to the bryoflora of southeast Asia that may also have relevance to the Wet Tropics bioregion include: Akiyama et al. (1991); Enroth (1990); Koponen and Norris (1983); Koponen et al. (1986); Mohamed (1998); Norris and Koponen (1987, 1990a, b); Reese et al. (1986a, b); Tan (1994); Yamaguchi (1993). Index Muscorum (Wijk et al. 1959–1969) has been useful for checking distributions.

Affinities with New Caledonia: All moss families occurring in New Caledonia are also present in Australia. The strong Southeast Asian element in north-east Queensland also extends to the Pacific; further to the west, the diversity of this element decreases. Previously it was thought that relationships between the species in New Caledonia and Australia were not close but recent studies have increased the number of species common to both and reduced the number of endemics in both countries (see Appendix 1). It is expected that this trend will continue.

Knowledge of distributions between the two is still limited for many genera. Pursell and Reese (1982) provided a list of species reported for New Caledonia. Of the 45 names listed in the genus *Macromitrium*, six occur in Australia (Vitt & Ramsay 1985a), in the Meteoriaceae six of the 16 species are found here (Streimann 1991a, b, c; 1992, 1993), in the Bryaceae six of 22 species including *Rosulabryum subfasciculatum* (Pursell & Reese 1982, Spence & Ramsay 1996), and in the Sematophyllaceae 11 of the 63 species reported for New Caledonia occur in Australia (Tan et al. 2002). Yamaguchi and Iwatsuki (1987) reduced the previous figure of 15 species of *Leucobryum*, including seven endemics, to four species with no endemics. Three of these species occur in Australia, including north-east Queensland. Pursell and Reese (1982) listed 39 taxa (also 50 nom. nud.) for *Fissidens*, of which 33 were endemics. A revision of the Fissidentaceae by Iwatsuki (1982) reduced the number of species to 23 including 13 endemics. Additional studies by Iwatsuki and Suzuki (1989) recorded 27 species and further reduced the number of endemics to three. *Nanobryum* *thorsbornei* (Stone 1990b) [= *Fissidens thorsbornei*], previously known only from Australia, was added to the list. In a discussion on the origins of the New Caledonian species, Iwatsuki (1990) reported six species of *Fissidens* with an Australian-New Caledonian distribution, but predicted an increase when northern Australian species were investigated. An Australian revision (Stone 1994a) has increased this number to about 23 *Fissidens* species now known to occur in both countries, including *F. rupicola*. Two additional Australian species have recently been added to the total for New Caledonia by Müller et al. (2003).

Ephemerum fimbriatum, previously known only from Australia, has been reported from New Caledonia by Matsui and Iwatsuki (1991). Most, if not all, of the small cleistocarpous mosses (in Pottiaceae, Ditrichaceae, Ephemeraceae and Archidiaceae) present in New Caledonia also occur in Australia. In addition *Viridivellus pulchellum* has also been recorded for New Caledonia (Iwatsuki pers. comm.)

It is evident that a considerable affinity exists between the terrestrial mosses of the north-east region of Australia and those of New Caledonia. While epiphytic pleurocarpous species appear at present to have less affinity in the two areas, further taxonomic studies may increase the relationships.

Affinities with Norfolk Island: Recently a survey of the mosses of Norfolk Island (Streimann 2002) has compared the distribution of species with those in Australia, New Zealand, and New Caledonia. Norfolk Island lies off the coast of Queensland approximately midway between New Caledonia and New Zealand. Affinities of mosses are strongest with Australia (91%) and New Zealand (66%), with only 29% of taxa in common with New Caledonia (Streimann 2002). Sixty nine species of mosses were listed for Norfolk Island, of which 38 (55%) have been recorded in the Wet Tropics bioregion. Just three of these taxa are restricted to Australia and Norfolk Island: *Erpodium hodgkinsoniae*, *Fissidens dietrichiae*, and *F. oblongifolius* var. *hyophilus*, and within Australia none are limited to Queensland (Streimann & Klazenga 2002).

Conclusions

In recent years there has been renewed interest in bryophytes; moss species have been described and their distributions in the Wet Tropics reported, generally associated with revisions of families or genera (e.g. Reese & Stone 1995; Eddy 1988, 1990, 1996, Streimann 1997, 1999, 2000a; Klazenga 2003). The majority of these have been published in dedicated bryological journals outside Australia (exceptions are e.g., Buck 1990, Klazenga 2003, Ramsay et al. 2002a), not easily accessible to general botanists and those involved in vegetation surveys. It is therefore not surprising that bryophytes have been frequently omitted from surveys of vegetation, perhaps because few researchers are familiar with their identification. This study summarises the available data on the mosses of the Wet Tropics bioregion and provides a useful and current checklist of moss species, identifying the areas in which the various species are distributed.

The Wet Tropics is one of the smallest bioregions in Queensland (Satler & Williams 1999), yet the mosses present represent 77.4% of all Queensland mosses. While the greatest number of collections has been made in the rainforests of the Wet Tropics bioregion, the area is still relatively unexplored, particularly in areas of lowland forest (Streimann 2001). Hopefully, publication of these studies will encourage and facilitate more useful investigation of this area. Other important and interesting regions of Queensland adjacent to the area in the north, south and west of the present studies with different rainfall, vegetation and soil types should eventually provide much of interest to bryologists.

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References

Adam, P. (1994) *Australian Rainforests*. Oxford Biogeography Series No.6. Oxford University Press, Oxford.

Akiyama, H., Koponen, T. and Norris, D.H. (1991) Bryophyte Flora of the Huon Peninsula, Papua New Guinea XLV. *Neolindbergia* (Prionodontaceae, Musci). *Acta Botanica Fennica* 143: 77–89.

Allen, B.H. (1981) A re-evaluation of the Sorapillaceae. *The Bryologist* 84: 335–338.

Allen, B.H. (1987) A revision of the Dicnemonaceae. *Journal of the Hattori Botanical Laboratory* 62: 1–100.

Ando, H. (1972) Distribution and speciation of the genus *Hypnum* in the circum-Pacific region. *Journal of the Hattori Botanical Laboratory* 35: 68–98.

Ando, H. (1977). Studies on the genus *Hypnum* Hedw. III. *Journal of Science of Hiroshima University* (ser. B. div. 2) 16: 1–46.

Arnold, G.O. and Fawckner. J.F. (1980) The Broken River and Hodgkinson Provinces *in* Henderson R.A. and Stephenson, P.J. (eds.) *The Geology and Geophysics of Northeastern Australia*, pp. 175–190. Geological Society of Australia, Queensland Division.

Bailey, F. (1893) Contributions to the Queensland Flora. *Queensland Botanical Bulletin* 8: 87–90.

Bailey, F.M. (1913) *Comprehensive Catalogue of Queensland Plants*. (mosses pp. 656–672) Govt. Printer, Brisbane.

Barlow, B.A. and Hyland, B.P.M. (1988) The origins of the flora of Australia's wet tropics. *Proceedings of the Ecological Society of Australia* 15: 1–17.

Bartram, E.B. (1939) Mosses of the Philippines. *Philippine Journal of Science* 68(1–4): 1–437.

Bartram, E.B. (1952) North Queensland mosses collected by L.J. Brass. *Farlowia* 4(1): 235–247.

Bates, J.W. (2000) Mineral nutrition, substratum ecology, and pollution *in* Shaw A.J. and Goffinet, B. (eds.) *Bryophyte Biology*, Cambridge University Press, Cambridge.

Beadle, N.C.W. & Costin, A.B. (1952). Ecological classification and nomenclature. *Proceedings of the Linnean Society of NSW* 77: 61–82.

Biggs, B.J.F. (1996) Hydraulic habitat of plants in streams. *Regulated Rivers: Research & Management* 12: 313–144.

Boden, R. and Given, D.R. (1995) Regional overview: Australia and New Zealand *in* Davis S.D., Heywood. V.H. and Hamilton, A.C. (eds.) *Centres of plant diversity: a guide and strategy for their conservation, Vol.2: Asia, Australasia and the Pacific*. World Wide Fund for Nature and IUCN, Cambridge.

Brotherus, V.F. and Watts, W.W. (1918) The mosses of North Queensland. *Proceedings of the Linnean Society of New South Wales* 43: 544–567.

Buck, W.R. (1979) A revision of the moss genus *Trachyphyllum* Gepp (Thuidiaceae). *Brittonia* 31: 379–394.

Buck, W.R. (1980) A reinterpretation of the Fabroniaceae: additions and corrections. *Journal of the Hattori Botanical Laboratory* 47: 45–55.

Buck, W.R. (1982) On *Meiothecium* (Sematophyllaceae). *Contributions of the University of Michigan Herbarium*. 15: 37–140.

Buck, W.R. (1990) A monograph of *Entodon* (Entodontaceae) in Australia, eastern Melanesia and southern Oceania. *Australian Systematic Botany* 3: 701–709.

Buck, W.R. & Crum, H. (1978) A re-interpretation of the Fabroniaceae. *Journal of the Hattori Botanical Laboratory* 44: 347–369.

Buck, W.R. & Tan B.C. (1989) The Asiatic genera of the Sematophyllaceae associated with *Trichosteleum*. *Acta Bryolichenologica Asiatica* 1(1,2): 5–19.

Buck, W. R. & Thiers, B. M. (1989) Review of bryological studies in the tropics *in* Campbell, D. G. and Hammond, H. D. (eds.) *Floristic Inventory of Tropical Countries*, New York Botanical Garden, New York.

Buck, W. R., Vitt D. H. & Malcolm W.M. (2002). *Key to the genera of Australian mosses*. Flora of Australia Supplementary Series, No. 14. Australian Biological Resources Study, Canberra.

Bureau of Meteorology (2001) Media release Friday, 5 January 2001 [Online]. Available: http://www.bom.gov.au/announcements/media_releases/ho/010105.shtml (accessed 9th August 2004).

Catcheside, D.G. (1980) *Mosses of South Australia*. Government Printer, South Australia.

Catcheside, D.G. & Frahm J.-P. (1985) Additions to the *Campylopus* flora of Australia. *Journal of Bryology* 13(3): 359–367.

Catcheside, D.G. and Stone I.G. (1988) The mosses of the Northern Territory, Australia. *Journal of Adelaide Botanic Gardens* 11(1): 1–17.

Crisp, M., Laffan, S., Linder, H.P. & Monro, A. (2001) Endemism in the Australian flora. *Journal of Biogeography* 28: 183–198.

Crisp, M.D., West, J.G. & Linder, H.P. (1999) Biogeography of the terrestrial flora. *Flora of Australia* 2nd edn. 1: 321–367. Australian Biological Resources Study, Canberra.

Crosby, M.R. & Magill R.E. (1978) *A dictionary of mosses*. Missouri Botanical Garden, Missouri.

Crosby, M.R., Magill R.E. & Bauer C. (1992) *Index of mosses 1963–1989*. Missouri Botanical Garden, Missouri.

Crum, H. (1971) Nomenclatural changes in the Musci. *The Bryologist* 74: 165–174.

Crum, H. (1986) A survey of the moss genus *Sclerodontium*. *Hikobia* 9: 289–295.

Crum, H. (1989) A reconsideration of the Leptostomataceae. *Journal of the Hattori Botanical Laboratory* 72: 127–139.

Crum, H. (1991) A partial classification of the Lembophyllaceae. *Journal of the Hattori Botanical Laboratory* 69: 313–322.

Dixon, H.N. (1938) Mosses of North Queensland. *North Queensland Naturalist* 6: 2–4.

Dixon, H.N. (1942) Additions to the mosses of North Queensland. *Proceedings of the Royal Society of Queensland*. 53(2): 23-40.

During, H.J, (1977) *A taxonomical revision of the Garovaglioideae (Pterobryaceae, Musci)*. Bryophytorum Bibliotheca 12. J. Cramer. Vaduz.

Eddy, A. (1988) *A handbook of Malesian mosses*. Vol 1. The Natural History Museum, London.

Eddy, A. (1990) *A handbook of Malesian mosses*. Vol 2. The Natural History Museum, London.

Eddy, A. (1996) *A handbook of Malesian mosses*. Vol 3. The Natural History Museum, London.

Eldridge, D. J., Semple, W.C. & Koen, T.B. (2000) Dynamics of cryptogam soil crusts in a derived grassland in south-eastern Australia. *Australian Ecology* 25: 232–240.

Ellis, L.T. (1985) A taxonomic revision of *Exodictyon* Card (Musci: Calymperaceae). *Lindbergia* 11: 9–31.

Ellis, L.T. (1991) *Calymperes schmidtii* Broth. in J. Schmidt and *C. subintegrum* Broth. in Schmidt, two distinct species from Malesia. *Journal of Bryology* 16: 589–593.

Enroth J. (1990) Bryophyte Flora of the Huon Peninsula, Papua New Guinea. XXXVI. Leucobryaceae (Musci). *Acta Botanica Fennica*. 139: 65–120.

Enroth, J. (1991) Notes on the Leskeaceae (Musci) 10. The taxonomic relationship of *Pinnatella marisi* with the description of *Caduciella* (Leptodontaceae). *Journal of Bryology* 16: 611–618.

Enroth, J. (1995) Taxonomy of *Cyptodon*, with notes on *Dendrocryphaea* and selected Australasian species of *Cryphaea* (Musci, Cryphaeaceae). *Fragmenta Floristica et Geobotanica* 40(1): 133–152.

Enroth, J. (1996) Amendments to Australasian *Cryphaeae* (Cryphaeaceae, Bryopsida). *Annales Botanici Fennici* 33: 39–44.

Fensham, R.J. & Streimann, H. (1997) Broad landscape relations of the moss flora from inland dry rainforest in north Queensland. *The Bryologist* 100: 56–64.

Foster, P. (2001) The potential negative impacts of global climate change on tropical montane cloud forests. *Earth-Science Reviews* 55(1–2): 73–106.

Frahm, J.-P. (1987a) A survey of *Campylopus* species in Australia. *Journal of Bryology* 14: 701–727.

Frahm, J.-P. (1987b) A revised list of the *Campylopus* species of the world. *Bryologische Beiträge* 7: 3–117.

Frahm, J.-P. (1988) The subantarctic and southern hemispheric species of *Campylopus* (Dicranaceae) with contributions to the origins and speciation of the genus. *Journal of the Hattori Botanical Laboratory* 64: 367–387.

Frahm, J.-P. (1990) *Campylopus laxitextus* Lac. new to Australia. *Journal of Bryology* 16: 305–306.

Frahm, J.-P. (1991) Taxonomische notizen zur Gattung *Campylopus* XVII *Cryptogamie Bryologie lichenologie* 19: 27–34.

Frahm, J.-P. (1992) A revision of the east-Asian species of *Campylopus*. *Journal of the Hattori Botanical Laboratory* 71: 133–164.

Frahm, J.-P. (1993) *Campylopus japonicus* new to North America north of Mexico. *The Bryologist* 96 (1):142-144.

Frahm, J.-P. (1994). A new synopsis of the Campylopus species from Australia. *Journal of Bryology* 1: 311–327.

Frahm, J.-P. (ed.) (2003) Manual of tropical bryology. *Tropical Bryology* 23: 1–196.

Frakes, L. (1999) Evolution of Australian environments. *Flora of Australia* 2nd edn. 1: 163–203, Australian Biological Resources Study, Canberra.

Franks, A.J. (2000) Biogeographical distribution of corticolous bryophytes in microphyll fern forests of south-east Queensland. *Proceedings of the Royal Society of Queensland* 109: 49–57.

Franks, A.J. & Bergstrom, D.M. (2000). Corticolous bryophytes in microphyll fern forests of south-east Queensland: distribution on Antarctic beech (*Nothofagus moorei*). *Austral Ecology* 25: 386–393.

Gillison, A.N. (1987) The 'dry' rainforests of Terra Australis *in* Australian Heritage Commission *The Rainforest Legacy* vol.1, pp. 305–321. AGPS, Canberra.

Goosem, S., Morgan, G. & Kemp, J.E. (1999) Wet Tropics, *in* Sattler, P. & Williams, R. (eds.) *The Conservation Status of Queensland's Bioregional Ecosystems*. Environmental Protection Agency, Queensland Government, Brisbane, pp. 7/1–7/73.

Gradstein, S.R. (1992) The vanishing tropical rain forest as an environment for bryophytes and lichen, *in* Bates, J.W. & Farmer, A.M. (eds.) *Bryophytes and lichens in a changing environment*, pp. 236–258 (Clarendon Press: Oxford).

Gradstein, S.R. (1997) The taxonomic diversity of epiphyllous bryophytes. *Abstracta Botanica* 21(1): 15–19.

Hedenäs, L. (2002) An overview of the family Brachytheciaceae (Bryophyta) in Australia. *Journal of the Hattori Botanical Laboratory* 92: 51–90.

Hicks, M. (1986) The geographic affinities of some north Queensland rainforest liverworts. (abstract). A.S.B.S. Symposium — *Australia's Wet Tropics* 25–27 August 1986 p. 37.

Hilbert, D.W., Ostendorf, B. & Hopkins, M.S. (2001) Sensitivity of tropical forests to climate change in the humid tropics of north Queensland. *Austral Ecology* 26: 590–603.

Hill, R.S. (ed) (1994) *History of Australian vegetation: Cretaceous to Recent* (Cambridge University Press: Cambridge).

Hyvönen, J. (1989a) A synopsis of genus *Pogonatum* (Polytrichaceae, Musci) *Acta Botanica Fennica* 138: 1–87.

Ireland, R.R. (1992) Studies on the genus *Plagiothecium* in Australasia. *The Bryologist* 95(2): 221–224.

Isoviita, P. (1986) *Cryptogonium* replaces *Pursellia* (Musci, Pterobryaceae). *Journal of the Hattori Botanical Laboratory* 60: 452–453.

Iwatsuki, Z. (1982) Speciation of the moss genus *Fissidens* in New Caledonia (a preliminary report). *Journal of the Hattori Botanical Laboratory* 52: 113–126.

Iwatsuki, Z. (1990) Origin of the New Caledonian bryophytes. *Tropical Bryology* 2: 139–148.

Iwatsuki, Z. & T. Suzuki. (1989) New Caledonian Fissidentaceae. *Journal of the Hattori Botanical Laboratory* 67: 267–290.

Iwatsuki, Z. & Tan, B. C. (1979) Checklist of Philippine mosses. *Philippine Journal of Biology* 8: 179–210.

Keto, A. & Scott K. (1986) *Tropical Rainforests of North Queensland, their Conservation and Significance*, pp. 159–162. Special Australia Heritage Publications No. 3, Australian Government Publishing Service, Canberra.

Kershaw, A.P. (1987). A record of the last interglacial–glacial cycle from north-east Queensland, Australia. *Nature* (Lond.) 272: 159–161.

Kitching, R. (ed.) (1987) Ecology of Australia's Wet Tropics. *Proceedings of the Ecological Society of Australia* Vol 15.

Klazenga, N. (1999) A revision of the Malesian species of *Dicranoloma* (Musci, Dicranaceae) *Journal of the Hattori Botanical Laboratory* 87: 1–130.

Klazenga, N. (2003) A revision of the Australasian species of Dicranoloma (Bryophyta, Dicranaceae). *Australian Systematic Botany* 16: 427–471.

Koponen, T. (1980) A synopsis of Mniaceae II. *Orthomnion*. *Annales Botanici Fennici* 16: 95–96.

Koponen, T. (1982) Mniaceae in Australasia and the Pacific. *Journal of the Hattori Botanical Laboratory* 52: 75–86.

Koponen, T. (1988) The phylogeny and classification of the Mniaceae and Rhizogoniaceae. (Musci). *Journal of the Hattori Botanical Laboratory* 64: 37–46.

Koponen, T. (1990) Bryophyte flora of Western Melanesia. *Tropical Bryology* 2: 149–160.

Koponen, T. & Norris D.H. (1983) Bryophyte Flora of the Huon Peninsula, Papua New Guinea II. Mniaceae (Musci). *Annales Botanici Fennici* 20: 31–40.

Koponen, T., Touw A. & Norris D.H. (1986) Bryophyte Flora of the Huon Peninsula XIV. Rhizogoniaceae (Musci). *Acta Botanica Fennica* 113: 1–24.

Kruijer, J. (2002) Hypopterygiaceae of the World. *Blumea* suppl. 13: 1–385.

Laaka-Lindberg, S., Korpelainen, H. & Pohjamo, M. (2003) Dispersal of asexual propagules in bryophytes. *Journal of the Hattori Botanical Laboratory* 93: 319–330.

Lai, Ming-Jou (1992) *Pseudospiridentopsis horrida* (Musci, Trachypodaceae) a neglected moss from Australia. *Journal of Japanese Botany* 67: 44–47.

Lewinsky, J. (1984) The genus *Orthotrichum* Hedw. (Musci) in Australasia: a taxonomic revision. *Journal of the Hattori Botanical Laboratory* 56: 369–460.

Lewinsky, J. (1990) *Zygodon* Hook. & Tayl. in Australasia: a taxonomic revision including studies of peristomes. *Lindbergia* 15(4): 109–139.

Lynch, A. J. J. & Neldner, V. J. (2000) Problems of placing boundaries on ecological continua — options for a workable national rainforest definition in Australia. *Australian Journal of Botany* 48: 511–530.

Martin, H.A. (1994) Australian Tertiary phytogeography: evidence from palynology *in* Hill, R.S. (ed.) *History of Australian Vegetation — Cretaceous to Recent*, pp.104–142 (Cambridge University Press: Cambridge).

Martin, H.A. (1998) Tertiary climatic evolution and the development of aridity in Australia. *Proceedings of the Linnean Society of New South Wales* 119: 115–130.

Matsui, T. & Iwatsuki Z. (1991) Notes on some cleistocarpous mosses in New Caledonia. *Hikobia* 11: 47–49.

Miller, N.G. & Manuel, M.G. (1982) *Trachyloma* (Bryophytina, Pterobryaceae): a taxonomic monograph. *Journal of the Hattori Botanical Laboratory* 51: 273–322.

Mohamed, H. (1998) Mosses of Sayup-Kinabalu Park, Sabah. *ASEAN Revue of Biodiversity and Environmental Conservation* Article V: 1–16.

Mohamed, H. M.A. (1979) A taxonomic study of *Bryum billardieri* Schwaegr. and related species. *Journal of Bryology* 10: 401–465.

Montfort, D. & Ek, R.C. (1990) *Vertical distribution and ecology of epiphytic bryophytes and lichens in a lowland rainforest in French Guiana.* Institute of Systematic Botany, Utrecht.

Morat, Ph., Veillon, J.-M., & MacKee, H.S. (1986) Floristic relationships of New Caledonian rainforest phanerogams. *Telopea* 2(6): 631–680.

Müller, F, Pursell R.A. & M.A.Bruggeman-Nanenga (2003) A contribution to the *Fissidens* (Musci, Fissidentaceae) of New Caledonia, including *F. cagoui sp. nov*. *Bryologist* 106(4): 578–582.

Norris, D.H. & Koponen, T. (1987) Bryophyte Flora of the Huon Peninsula, Papua New Guinea XX. Fissidentaceae, Mitteniaceae, Phyllodrepaniaceae and Sorapillaceae (Musci). *Annales Botanici Fennici* 24: 177–219.

Norris, D.H. & Koponen, T.(1989a) The Bryophyte Flora of the Huon Peninsula, Papua New Guinea: XXVIII. Pottiaceae (Musci). *Acta Botanica Fennica* 137: 81–138.

Norris, D.H. & Koponen T. (1989b) Typification of *Dicranoloma* Ren. a small genus of mosses from northern Australia and New Caledonia. *Acta Bryolichenologica Asiatica* 1(1,2): 1–4.

Norris. D.H. & Koponen T. (1990a) Bryophyte Flora of the Huon Peninsula, Papua New Guinea. XXIII. Leskeaceae and Fabroniaceae (Musci) plus corrigenda and addenda to previous papers. *Annales Botanici Fennici* 27: 1–12.

Norris, D.H. & Koponen T. (1990b) Bryophyte Flora of the Huon Peninsula, Papua New Guinea XXXV. Dicranaceae and Dicnemonaceae (Musci). *Acta Botanica Fennica* 139: 1–64.

Norris, D.H & Robinson H. (1979) The systematic position of *Bryobrothera crenulata*. *Bryologist* 82(2): 305–309.

Nott, J.F., Thomas, M.F. & Price. D.M. (2001) Alluvial fans, landslides and Late Quaternary climatic change in the wet tropics of northeast Queensland. *Australian Journal of Earth Sciences*. 48(6): 875–882.

Nowak, H. (1980) Revision der Laubmoosgattung *Mitthyridium* (Mitten) Robinson für Ozeanien (Calymperaceae). *Bryophytum Bibliotheca* 201–236.

Ochi, H. (1970) A revision of the subfamily Bryoideae in Australia, Tasmania, New Zealand and the adjacent islands. *Journal of the Faculty of Education, Tottori University of Natural Sciences* 21: 7–67.

Ochi, H. (1973) Supplement to the family Bryoideae (Musci) in Australia and New Zealand. *Hikobia* 6: 217–223.

Ochi, H. (1980) A revision of the neotropical Bryoideae, Musci (first part). *Journal of the Faculty of Education, Tottori University of Natural Sciences* 29: 49–154.

Ochi, H. (1982). A phytogeographical consideration of Australasian Bryoideae in relation to those in other continents. *Journal of the Hattori Botanical Laboratory* 52: 65–73.

Ochyra, R. (1986) *Touwia laticostata*, a remarkable new genus and species of moss from Queensland, Australia. *Journal of Bryology* 14: 103–108.

Piipo, S. & Koponen, T. (2003) Review of the bryofloristic connections of New Guinea Island. *Telopea* 10 (1): 467–476.

Pócs, T. (1982) Tropical Forest Bryophytes *in* Smith, A. J. E (ed.), *Bryophyte Ecology*, Chapman and Hall, London pp. 59–104.

Pursell, R.A. & Reese W.D (1982) The mosses reported from New Caledonia. *Journal of the Hattori Botanical Laboratory* 53: 449–482.

Ramsay, H.P. (1987) Studies on the reproductive biology of some mosses from the Australian wet tropics. *Proceedings of the Ecological Society of Australia* 15: 273–279.

Ramsay, H.P. & Schofield, W.B (1987) Preliminary studies in the Sematophyllaceae (Bryopsida) from North Queensland. *Australian Systematic Botany Society Newsletter* 50: 7–12.

Ramsay, H.P., Schofield, W.B. & Tan, B.C. (2002a) The genus *Taxithelium* Spruce (Bryopsida, Sematophyllaceae) in Australia. *Australian Systematic Botany* 15: 1–14.

Ramsay, H.P., Schofield, W.B. & Tan, B.C. (2002b) The family Sematophyllaceae (Bryopsida) in Australia. Part 1. Introduction, family data, key to genera, and the genera *Wijkia, Acanthorrhynchium, Trismegistia* and *Sematophyllum*. *Journal of the Hattori Botanical Laboratory* 92: 1–50.

Ramsay, H.P., Schofield, W.B. & Tan, B.C. (2004) The family Sematophyllaceae (Bryopsida) in Australia. Part 2. *Acroporium, Clastobryum, Macrohymenium, Meiotheciella, Meiothecium, Papillidiopsis, Radulina, Rhaphidorrhynchium, Trichosteleum, Warburgiella*. *Journal of the Hattori Botanical Laboratory* 95: 1–60.

Ramsay. H.P. & Seur, J. (1994) *Register of type specimens of mosses in Australian Herbaria.* Flora of Australia Supplementary Vol. 2. Australian Biological Resources Study, Canberra 1–150.

Ramsay, H.P., Streimann, H., Ratkowsky, A.V., Seppelt, R. D. & Fife, A.J. (1986). Australasian alpine bryophytes, *in*. Barlow B. (ed). *Flora and Fauna of Alpine Australasia.* CSIRO and A.S.B.S., Canberra.

Ramsay, H.P., Streimann, H. & Harden, G.M. (1987) The bryoflora of Australasian rainforests. *Symposia Biologica Hungarica*. 35: 605–620.

Ramsay, H.P., Streimann H. & .Vitt D.H. (1995) Cytological studies on mosses from Papua New Guinea. 1. Introduction and family Orthotrichaceae. *Tropical Bryology* 11: 151–160.

Reese, W.D. (1989) Two new taxa of *Syrrhopodon* (Musci: Calymperaceae) from Australia. *The Bryologist* 93(3): 302–304.

Reese, W.D. (1992) *Syrrhopodon cyrtacanthus*, a new species of moss from Australia. *The Bryologist* 95 (1): 94–96.

Reese, W.D., Koponen, T. & Norris, D.H. (1986a) Bryophyte flora of the Huon Peninsula, Papua New Guinea X1X. *Calymperes, Syrrhopodon* and *Mitthyridium* (Calymperaceae, Musci). *Acta Botanica Fennica* 133: 151–202.

Reese, W.D., Mohamed H. & Mohamed A.D (1986b) A synopsis of *Mitthyridium* (Musci: Calymperaceae) in Malaysia and adjacent regions. *The Bryologist* 89: 49–58.

Reese, W.D. & Stone I.G. (1987) New records of Australian Calymperaceae and keys to Australian species of *Calymperes, Mitthyridium* and *Syrrhopodon*. *Journal of Bryology* 14: 487–493.

Reese, W.D. & Stone I.G. (1995) The Calymperaceae of Australia. *Journal of the Hattori Botanical Laboratory* 78: 1–40.

Richards, P.W. (1984) The ecology of tropical forest bryophytes *in* Schuster, R.M. (ed.) *New Manual of Bryology*, Chap. 21 pp. 1233–1270. Hattori Botanical Laboratory, Nichinan, Japan.

Salazar Allen, N. (1993) A revision of the pantropical moss genus *Leucophanes* Brid. *Bryophytorum Bibliotheca* 46: 1–281.

Sattler, P. and Williams, R. (eds.) (1999) *The conservation status of Queensland's bioregional ecosystems*. Environmental Protection Agency, Queensland Government, Brisbane.

Schultze-Motel, W. (1970) Ephemeropsidae — eine neuer name fur eine familie der Moose. *Taxon* 19: 252–252.

Schuster, R.M. (1986) Referees' evaluation of Keto, A. & K. Scott: *Tropical Rainforests of North Queensland: Their Conservation and Significance*. Special Australian Heritage Publication No. 3. Australian Government Printing Service, Canberra pp. 159–163.

Scott, G.A.M. (1994) Liverworts and Mosses *in* Entwisle, T.J. (ed.) *Aquatic Cryptogams of Australia*, Australian Society for Limnology, Special Publication No.10, National Herbarium of Victoria, South Yarra.

Scott, G.A.M. & Stone I.G. (1976) *The Mosses of Southern Australia* (Academic Press: London).

Shaw, A.J. (1985) Nomenclatural changes in the Bryaceae, subfamily Mielichhoferioideae. *The Bryologist* 88: 28–30.

Shaw, A.J. & Goffinet, B. (eds.) (2000) *Bryophyte Biology* (Cambridge University Press: Cambridge).

Smith, A.J.E. (1982) Epiphytes and epiliths *in* Smith, A.J.E. (ed.) *Bryophyte Ecology* pp. 191–227 (Chapman & Hall: London).

Specht, R.L. (1970) Vegetation *in* Leeper, G.W. (ed.) *The Australian Environment*, 4th edition (CSIRO and Melbourne University Press, Melbourne).

Specht, R.L. & Specht, A. (1999) *Australian plant communities* (Oxford University Press: Oxford).

Spence, J.R. (1996) *Rosulabryum genus novum* (Musci, Bryaceae). *The Bryologist* 99: 221–225.

Spence, J.R., & Ramsay H.P. (1996) New and interesting species of the family Bryaceae (Bryopsida) from Australia. *Journal of the Adelaide Botanic Gardens* 17: 107–118.

Spence, J.R. & Ramsay H.P. (2002) A revision of the genus *Anomobryum* Schimp. (Bryopsida, Bryaceae) in Australia. *Telopea* 9(4): 777–792.

Spence, J.R. & Ramsay, H.P. (2005) *Flora of Australia* Bryophytes (mosses part 1) vol. 51 Bryaceae (in press).

Stanton, J.P. & Stanton, D.J. (2000) *Wet Tropics Vegetation Mapping Project*. Report to the Wet Tropics Management Authority Volume1: December 1997 – January 1999.

Stanton, J.P. & Stanton, D.J. (2001a) *Wet Tropics Vegetation Mapping Project*. Report to the Wet Tropics Management Authority Volume 2: December1997 – May 2000.

Stanton, J.P. & Stanton, D.J. (2001b) *Wet Tropics Vegetation Mapping Project*. Report to the Wet Tropics Management Authority Volume 3: May 2000 – September 2001.

Stephenson, P.J., Griffin, T.J. & Sutherland, F.L. (1980). Cainozoic volcanism in northeastern Australia, *in* Henderson, R.A. and Stephenson, P.J. (eds.) *The geology and geophysics of northeastern Australia*. pp. 349–374. Geological Society of Australia, Queensland Division, Brisbane.

Stone, I.G. (1975) *Trachycarpidium* in Queensland, Australia. *Muelleria* 3: 122–129.

Stone, I.G. (1976) A remarkable new moss from Queensland, Australia — *Viridivellus pulchellum*, new genus and species (new family Viridivelleraceae). *Journal of Bryology* 9: 21–31.

Stone, I.G. (1980) *Weissia* subgenus *Astomum* in Australia and some comments on the affinity of *Viridivellus*. *Journal of Bryology* 11: 231–243.

Stone, I.G. (1982a). *Erpodium australiense* (Erpodiaceae), a new species from Australia. *Journal of Bryology* 12: 191–197.

Stone, I.G. (1982b) *Nanobryum thorsbornei*, a remarkable new moss from Australia. *Journal of Bryology* 12: 199–208.

Stone, I.G. (1982c) Some new and noteworthy records of mosses mostly from Queensland. *Austrobaileya* 1: 511–520.

Stone, I.G. (1983a) A re-evaluation of the species of *Mesochaete* Lindb. (Rhizogoniaceae). *Journal of Bryology* 12: 351–357.

Stone, I.G. (1983b) *Fissidens traversii*, a new species from Queensland, Australia. *Journal of Bryology* 12: 359–364.

Stone, I.G. (1983c) *Buxbaumia* in Australia, including one new species, *B. thorsborneae*. *Journal of Bryology* 12: 541–552.

Stone, I.G. (1983d) *Fissidens gymnocarpus*, a new species from Queensland, Australia. *Journal of Bryology* 12: 552–557.

Stone, I.G. (1984a.) *Uleobryum curtisii* sp. nov. (Pottiaceae) from Queensland, Australia. *Journal of Bryology* 13: 19–24.

Stone. I.G. (1984b) *Archidium wattsii* comb. nov. in Australia. *Journal of Bryology* 13: 153–157.

Stone, I.G. (1984c) *Fissidens henryae*, a new species from Queensland, Australia. *Journal of Bryology* 13: 159–162.

Stone, I.G. (1985a) *Archidium thalliferum* sp. nov. with a persistent cushion-shaped protonema unique in Musci. *Journal of Bryology* 13: 345–352.

Stone, I.G. (1985b) *Archidium minutissimum*, a new species from Queensland, Australia. *Journal of Bryology* 13: 353–357.

Stone, I.G. (1985c) New records of mosses in Australia. *Journal of Bryology* 13: 475–478.

Stone, I.G. (1986) A comparison of the species of *Fissidens* subgenus *Aneuron* in Australia. *Journal of Bryology* 14: 319–325.

Stone, I.G. (1987a) *Fissidens sufflatus* and *Fissidens pseudopallidus* spp. nov. (Fissidentaceae) from Queensland, Australia. *Memoirs of the New York Botanic Gardens* 45: 627–634.

Stone, I.G. (1987b) *Tristichella dimorpha* (Sematophyllaceae), a new species from Queensland. *Journal of Bryology* 14(4): 691–700.

Stone, I.G. (1990a) Nomenclatural changes and a new moss species in Australia, including a description of the protonema of Calomnion. *Journal of Bryology* 16: 261–263.

Stone, I.G. (1990b) *Fissidens* sections Crispidium, Amblyothallia, Serridium and Pachyfissidens in Australasia: some taxonomic changes and a key to species. *Journal of Bryology* 16: 245–260.

Stone, I.G. (1990c) Nomenclatural changes and a new moss record in Australia: including a description of the protonema of *Calomnion*. *Journal of Bryology* 16: 261–273.

Stone, I.G. (1991) *Fissidens linearis* Brid. and its synonyms. *Journal of Bryology* 16: 403–405.

Stone, I.G. (1994a) Miscellaneous studies on Australian *Fissidens*. *Journal of Bryology* 18: 159–167.

Stone, I.G. (1994b) *Fissidens* section Gennlaria Müll.Hal. in Australia. *Journal of Bryology* 18: 169–180.

Stone, I.G. (1996) A revision of Ephemeraceae in Australia. *Journal of Bryology* 19: 279–295.

Stone, I.G. (1997) A revision of Erpodiaceae with particular reference to Australian taxa. *Journal of Bryology* 19: 485–502.

Stone, I.G. & Catcheside, D.G. (1993) Two new species, *Fissidens oblatus* and *F. babyinbarus* from Queensland, Australia. *Journal of Bryology* 17: 621–626.

Stone, I.G. & Scott G.A.M. (1973) Name changes in Australian mosses. *Journal of Bryology* 7: 603–605.

Stoneburner, A. & Wyatt, R. (1993) Census of the mosses of Western Australia. *Bryologist* 96(1): 86–101.

Streimann, H. (1991a) Taxonomic studies on Australian Meteoriaceae (Musci) 1. Introduction and the genus *Papillaria*. *Journal of the Hattori Botanical Laboratory* 69: 203–256.

Streimann, H. (1991b) Taxonomic studies on Australian Meteoriaceae (Musci) 2: The genera *Aerobryopsis*, *Barbella*, *Floribundaria*, *Meteoriopsis*, *Meteorium* and *Weymouthia*. *Journal of the Hattori Botanical Laboratory* 69: 277–312.

Streimann, H. (1991c) Taxonomic studies on Australian Meteoriaceae (Musci). 3. *Papillario nitens* (Hook. f. and Wils.) Sainsb. *Journal of the Hattori Botanical Laboratory* 70: 43–50.

Streimann, H. (1992) Moss genus *Papillaria* (Meteoriaceae) in the Pacific. *Journal of the Hattori Botanical Laboratory* 71: 83–112.

Streimann, H. (1993) *Barbella trichophora*, an older name *for B. cubensis* (Musci: Meteoriaceae). *The Bryologist* 96(2): 223–225.

Streimann, H. (1994) Conservation status of bryophytes in eastern Australia. *Tropical Bryology* 9: 117–122.

Streimann, H. (1997) Taxonomic studies on Australian Hookeriaceae (Musci). 1: Introduction and the genera *Achrophyllum*, *Callicostella*, *Chaetomitrium* and Cyclodictyon *Journal of the Hattori Botanical Laboratory* 82: 281–304

Streimann, H. (1999) Taxonomic studies on Australian Hookeriaceae (Musci). 2: The genera *Distichophyllum* and *Bryobrothera*. *Journal of the Hattori Botanical Laboratory* 86: 89–119.

Streimann, H. (2000a) Taxonomic studies on Australian Hookeriaceae (Musci). 3. The genera *Calyptrochaeta*, *Daltonia*, *Hookeriopsis*, and *Sauloma*. *Journal of the Hattori Botanical Laboratory*. 88: 101–138.

Streimann, H. (2000b) Australasia, *in* Hallingbäck and Hodgetts, N. (eds.) *Mosses, Liverworts and Hornworts: Status Survey and Conservation Action Plan for Bryophytes*, pp.22–27. IUCN Publications, Cambridge.

Streimann, H. (2001) Taxonomic studies on Australian Hookeriaceae (Musci). 4. Summary and bryogeographic studies. *Journal of the Hattori Botanical Laboratory* 90: 211–220.

Streimann, H. (2002) *The mosses of Norfolk Island*. Australian Biological Resources Study Publications, Canberra.

Streimann, H. & Klazenga, N. (2002) *Catalogue of Australian Mosses*. Flora of Australia Supplementary series Number 17. Australian Biological Resources Study, Canberra.

Suren, A. (1993) Bryophytes and associated invertebrates in first-order alpine streams of Arthur's Pass, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 27: 479–494.

Syed, H. (1973) A taxonomic study of *Bryum capillare* Hedw. and related species. *Journal of Bryology* 7: 265–326.

Tan, B.C., (1994) The bryophytes of Sabah (North Borneo) with special reference to the BRYOTROP transect of Mount Kinabalu. The genus *Acroporium* (Sematophyllaceae, Musci) in Borneo, Java and the Philippines. *Willdenowia* 24 (1994): 255–294.

Tan, B.C. (1998) Noteworthy disjunctive patterns of Malesian mosses *in* Hall, R. and Holloway, J.D. (eds.) *Biogeography and Geological Evolution of SE Asia*, pp. 235–241 (Backhuys Publishers: Leiden).

Tan, B.C. & Iwatsuki, Z. (1991) A new annotated Philippine moss checklist. *Harvard Papers in Botany* 3: 1–64.

Tan, B.C. & Iwatsuki, Z. (1993) Checklist of Indochinese mosses. *Journal of the Hattori Botanical Laboratory* 74: 325–405.

Tan, B.C. & Iwatsuki, Z. (1999) Four hotspots of moss diversity in Malesia. *Bryobrothera* 5: 247–252.

Tan B.C., Iwatsuki, Z. & Norris, D.H. (1992) Lectotypification of *Clastobryum indicum* and *C. inconspicuum*. *Hikobia* 11: 147–152.

Tan, B.C. & Pócs, T. (2000) Bryogeography and conservation of bryophytes, *in* Shaw, A.J. & Goffinet, B. (eds.) *Bryophyte Biology*, pp. 403–448 (Cambridge University Press: Cambridge).

Tan, B.C., Ramsay H.P. & Schofield W.B. (1996) A contribution to Australian Sematophyllaceae (Bryopsida). *Australian Systematic Botany* 9: 319–327.

Tan, B.C., Schofield W.B. & Ramsay H.P. (1998) Miscellanies of Australian Sematophyllaceae with a new genus *Meiotheciella*. *Nova Hedwigia* 67: 213–223.

Tangney, R.S. (1996) A taxonomic revision of the genus *Camptochaete* Reichdt *Journal of the Hattori Botanical Laboratory* 81: 53–122.

Tangney, R.S. (1997) A generic revision of the Lembophyllaceae. *Journal of the Hattori Botanical Laboratory* 81: 123–154.

Thaitong, O. (1984) Bryophytes of the mangrove forest. *Journal of the Hattori Botanical Laboratory* 56: 85–87.

Touw, A. (1971) A taxonomic revision of Hypnodendraceae (Musci). *Blumea* 19: 211–354.

Touw, A. (1992) A survey of the mosses of the Lesser Sunda Islands (Nusa Tengaarra), Indonesia. *Journal of the Hattori Botanical Laboratory* 71: 289–366.

Touw, A. (2001a) A review of the Thuidiaceae (Musci) and a realignment of taxa traditionally accommodated in *Thuidium* sensu amplo (*Thuidium* Schimp., *Thuidiopsis*(Broth) M. Fleisch and *Pelekenium* (Mitt), including *Aequatorialla* gen. nov. and *Indothuidium* gen. nov. *Journal of the Hattori Botanical Laboratory* 90: 167–209.

Touw, A. (2001b) A taxonomic revision of the Thuidiaceae (Musci) of tropical Asia, the Western Pacific, and Hawaii. *Journal of the Hattori Botanical Laboratory* 91: 1–136.

Touw, A. & Falter-van den Haak L. (1989) A revision of Australasian Thuidiaceae (Musci), with notes on species of adjacent regions. *Journal of the Hattori Botanical Laboratory* 67: 1–57.

Tracey, J.G. (1982) *The vegetation of the humid tropical region of North Queensland* (CSIRO: Melbourne).

Tracey, J.G. & Webb L.J. (1975) *Vegetation of the humid tropical region of North Queensland*. (15 maps at 1:100,000 scale and key) CSIRO, Australian Long Pocket Labs Indooroopilly, Qld.

Vitt, D.H. (1984) Classification of the Bryopsida, *in* R.M. Schuster *New Manual of Bryology*, vol. 2: pp. 696–759. Hattori Botanical Laboratory.

Vitt, D.H. (1989) The genus *Schlotheimia* (Orthotrichaceae: Bryopsida) in Australia and New Zealand. *Bryologist* 92(3): 282– 298.

Vitt, D. H. & Glime, J. M. (1984) The structural adaptations of aquatic Musci. *Lindbergia* 10: 95–110.

Vitt, D.H. & Ramsay H.P. (1985a) The *Macromitrium* complex in Australasia (Orthotrichaceae: Bryopsida) Part I. Taxonomy and Phylogenetic relationships. *Journal of the Hattori Botanical Laboratory* 59: 325–451.

Vitt, D.H. & Ramsay H.P. (1985b) The *Macromitrium* complex in Australasia (Orthotrichaceae: Bryopsida) Part II. Distribution, Ecology and Paleogeography. *Journal of the Hattori Botanical Laboratory* 59: 453–468.

Van Zanten, B.O. (1973) A taxonomic revision of the genus *Dawsonia* R. Brown. *Lindbergia* 2: 1–48.

van Zanten, B.O. & Hofman, A. (1995) On the origin and taxonomic status of *Racopilum chilense* (Musci, Racopilaceae) by using electrophoretic analysis. *Fragm. Flor. Geobot.* 40(1): 405–416.

van Zanten, B.O. & Pócs T. (1981) Distribution and dispersal of bryophytes, *in* W. Schultze-Motel (Ed.) *Advances in Bryology* volume 1: 479–562.

Walker, D. (1990) Directions and rates of rainforest processes *in* Webb, L.J. & Kikkawa, J. (eds.) *Australian Tropical Rainforest: Science – Values – Meaning*. pp. 23–32, CSIRO Publishing, East Melbourne.

Watts, W.W. & Whitelegge T. (1902) Census Muscorum Australiensium. *Proceedings of the Linnean Society of New South Wales* 27 (Supplement): 1–90.

Watts, W.W. & Whitelegge T. (1906) Census Muscorum Australiensium. *Proceedings of the Linnean Society of New South Wales* 30 (Supplement): 91–163.

Webb, L.J. (1959) A physiognomic classification of Australian rainforests. *Journal of Ecology* 47: 551–570.

Webb, L.J. (1968). Environmental relationships of the structural types of Australian rain forest vegetation. *Ecology* 49(2): 296–311.

Webb, L.J. (1978). A general classification of Australian rainforests. *Australian Plants* 9(76): 349–363.

Webb, L.J. & Tracey J.G. (1981) Australian Rainforests: Patterns and Change, *in* A. Keast (ed.) *Ecological Biogeography of Australia*. pp. W. Junk. The Hague.

Webb, L.J., Tracey, J.G. & Jessup, L.W. (1986) Recent evidence for autochthony of Australian tropical and subtropical rainforest elements. *Telopea* 2(6): 575–590.

Webb, L.J. & J.G. Tracey (1994) The rainforests of northern Australia *in* R.H. Groves (ed) *Australian Vegetation* 2nd edition. pp. 108–109 (Cambridge University Press).

Wijk. R. van der, Margadant, W.D. & Florschutz, P.A. (1959–1969) *Index Muscorum* (5 vols) International Bureau Plant Taxonomy, Utrecht.

Williams, M.A.J., Dunkerley, D.L., De Deckker P., Kershaw, A.P. & Stokes, T. (1993) *Quaternary Environments* (Edward Arnold: London).

Williams, S.E., Bolitho, E.E. & Fox, S. (2003) Climate change in Australian rainforests: an impending environmental catastrophe. *Proceedings of the Royal Society London* B270, 1887–1892.

Wilmott, W. F. & Stephenson, P.J. (1989) *Rocks and landscapes of the Cairns district* (Queensland Department of Mines: Brisbane).

Windolf, J. (1987) Annotated checklist of Queensland hepaticae. *Austrobaileya* 2(4): 380–400.

Windolf, J. (1989) Bryophytes in the sub-tropical mangrove community. *Austrobaileya* 3(1): 103–107.

Wolf, J.H.D. (1993) Diversity patterns and biomass of epiphytic bryophytes and lichens along an altitudinal gradient in the northern Andes. *Annals of the Missouri Botanic Gardens* 80: 928–960.

WTMA (2002) *Wet Tropics Management Authority Annual Report 2001–2002*, pp. 22–75.

Yamaguchi, T. (1993) A revision of the genus *Leucobryum* in Asia. *Journal of the Hattori Botanical Laboratory* 73: 1–124.

Yamaguchi, T. & Iwatsuki, Z. (1987) New Caledonian Leucobryaceae (Musci). *Journal of the Hattori Botanical Laboratory* 63: 473–491.

Zander, R.H. (1993) Genera of the Pottiaceae: mosses of harsh environments. *Bulletin of the Buffalo Society of Natural Science* 32: 1–378.

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Appendix 1. List of mosses of the Wet Tropics bioregion, north-east Queensland.

Species: The species list includes new records and new species. Some earlier names may be in synonymy and these are listed in Streimann and Klazenga (2002). If more recently published, they are included here.

Distribution: showing relationships in Australia and affinities to areas adjacent to Australia. Distributions in other Australian states and territories are available in Streimann & Klazenga (2002).

WT= Wet Tropics endemics

AU = Australian endemics

NS = New species for Australia

NR = New records for the Wet Tropics

S.E.Asia = species present particularly in parts of Malesia, some in Papua New Guinea.

NZ = New Zealand

OC = Oceania

New Caled. = New Caledonia

Location: within the Wet Tropics bioregion

The Wet Tropics bioregion is subdivided into a series of provinces (Sattler & Williams 1999). The numbers used here relate to the list of provinces according to Goosem et al. (1999).

Province 1. Herbert: Low rainfall, delta of the Herbert River, Quaternary alluvium; alluvial plains with relic stream channels, low stream levees and prior streams associated with the coastal escarpment between the Cardwell Range and Bluewater Creek; open forests and woodlands.

Province 2. Tully: High rainfall, Quaternary alluvium: alluvial plains, channels, levees, lagoons and piedmont fans; mesophyll rainforest.

Province 3. Innisfail: High rainfall, Quaternary alluvium, some basalt and metasediments; undulating low hills, alluvial plains, channels, levees, lagoons; mesophyll rainforest, fan palm and feather palm rainforests, woodlands.

Province 4. Atherton: Moderately high rainfall, 700–1000 m altitude; tableland area dominated by basalt plains, subtropical climate; mainly fragmented mesophyll rainforest.

Province 5. Paluma-Seaview: Relatively low rainfall, 800–900+ m elevation; granitic southern ranges, separated from the northern provinces by the Herbert River Gorge; simple notophyll rainforest

Province 6. Kirrama-Hinchinbrook: Moderately high rainfall. Steep environmental gradients associated with steep slopes, waterfalls, shallow soils and complex vegetation including simple and complex notophyll rainforest, mesophyll vine forest, tall open forest and woodland. Subdivided for the purposes of this study into:

- 6a. Cardwell and Kirrama Ranges: Rainfall moderate
- 6b. Hinchinbrook Island: Rainfall variable, to 3500 mm per annum

Province 7. Bellenden Ker-Lamb Range: Very high rainfall, high altitudes to 1600+ m; wet and cloudy upland granitic massifs; mostly rainforest; a major centre of endemism in the bioregion.

Province 8. Macalister (north and west of Cairns): Moderate rainfall; undulating tableland bounded by a steep dissected escarpment falling to a narrow coastal plain; includes the Black Mountain corridor; vegetation mixed.

Province 9. Daintree–Bloomfield: Variable rainfall; a complex province, likely to be subdivided in the future- includes Mt Carbine, Windsor and Big Tablelands, Mount Finnigan, Thornton Peak, Mt Lewis.

Species	Location	Distribution
Acanthorrhynchium papillatum (Harv.) M.Fleisch.	1, 2, 6b	S.E.Asia
Achrophyllum dentatum (Hook. f. & Wilson) Vitt & Crosby	4	S.E.Asia, PNG, NZ
Acroporium lamprophyllum Mitt. var. *percaudatum* (E.B.Bartram) B.C.Tan, H.P.Ramsay & W.B.Schofield	2, 5, 6a, 9	S.E. Asia, NS
Acroporium microcladon (Dozy & Molk.) B.C.Tan var. *rhizogemmae* B.C.Tan, W.B.Schofield & H.P.Ramsay (includes specimens identified as *C. conspicuum* M. Fleisch.)	2, 4, 5, 6a, 7, 9	S.E.Asia NS
Acroporium stramineum (Reinw. & Hornsch.) M.Fleisch. = *A. erythropodium* (Hampe) Broth. (AU); *Rhynchostegium erythropodium* (Hampe) Mitt.; *Sematophyllum erythropodium* (Hampe) A. Jaeger	4, 5 6a, 7, 9	S.E.Asia

Acroporium strepsiphyllum (Mont.) B.C.Tan	5, 6a, 9	S.E.Asia, **NS**
Aerobryopsis longissima (Dozy & Molk.) M.Fleisch.	1, 2, 3, 4, 5, 6a, 7, 9	S.E. Asia
Anoectangium aestivum (Hedw.) Mitt.	3	Asia
Archidium brevinerve P. de la Varde	2	Equatorial Africa
Archidium capense Hornsch.	2	Southern Africa
Archidium clarksonianum I.G.Stone	5	AU
Archidium elatum Dixon & Sainsbury	2, 6	**NR**
Archidium microthecium *Dixon & P. de la Varde*	2	Southern Africa & India
Archidium minutissum I.G. Stone	9	WT
Archidium ohioense Schimp. ex Müll.Hal.	4	Cosmopolitan, **NS**
Archidium rothii Watts ex G.Roth	1, 2, 3, 8, 9	AU
Archidium species A	2	AU
Archidium species B	3	AU
Archidium species C	2, 3, 8, 9	AU
Arthrocormus schimperi (Dozy & Molk.) Dozy & Molk.	2, 3, 7, 9	S.E.Asia
Barbellopsis trichophora (Mont.) W.R Buck	1, 2, 3, 4, 5, 6a, 7, 8, 9	S.E.Asia
Barbula subcalycina Mull Hal.	4	AU
Bartramia mossmaniana Müll.Hal.	7	South America
Bescherellia elegantissima Duby	2, 4, 5, 6a, 9	New Caled.
Brachymenium nepalense Hook.	2, 3, 4, 5 6a, 7, 9	Paleotrop. S.E. Asia, OC
Brachythecium salebrosum (F.Weber & D.Mohr) Schimp.	4	Southern Africa, NZ,
Braithwaitea sulcata (Hook.) A.Jaeger & Sauerb.	4	NZ
Breutelia affinis (Hook.) Mitt.	6a	NZ
Bryobrothera crenulata (Broth. & Paris) Thér.	5, 6a, 6b, 7, 9	S.E.Asia, Melanesia
Bryum argenteum Hedw.	1, 2, 3, 5, 6a, 7, 9	S.E.Asia
Bryum auratum Mitt. Syn: *Anomobryum auratum*	4, 5	S.E.Asia
Bryum lanatum (P.Beauv.) Brid. Syn: *Anomobryum lanatum*	1, 2, 3,4, 5, 6a, 7, 9	S.E.Asia
Buxbaumia colyerae Burges	7	AU
Buxbaumia thorsorneae I. G. Stone	7	WT
Caduciella mariei (Besch.) Enroth	9	S.E.Asia
Callicostella papillata (Mont.) Mitt. var. *papillata*	9	S.E.Asia
Callicostella papillata (Mont.) Mitt. var. *prabaktiana* (Müll.Hal.) Streimann	3, 8, 9	S.E.Asia
Calymperes afzelii Sw.	1, 2, 3, 5, 6a, 9	S.E.Asia, Pantropical
Calymperes boulayi Besch.	8	**NR**, S.E.Asia
Calymperes couguiense Besch.	2, 3, 7, 9	S.E.Asia
Calymperes crassinerve (Mitt.) A. Jaeger	2, 3, 9	S.E.Asia
Calymperes erosum Müll.Hal.	1, 3, 4, 6b, 7, 9	S.E.Asia, Pantropical
Calymperes graeffeanum Müll.Hal.	1, 2, 3, 4, 6a, 6b, 7, 8, 9	S.E.Asia
Calymperes lonchophyllum Schwägr.	2, 9	S.E.Asia
Calymperes moluccense Schwägr.	2, 3, 7, 9	S.E.Asia
Calymperes motleyi Mitt.	1, 2, 5, 9	S.E.Asia
Calymperes porrectum Mitt.	9	S.E.Asia
Calymperes serratum A. Braun ex Müll.Hal.	3, 4, 7, 9	S.E.Asia
Calymperes strictifolium (Mitt.) G. Roth	3	S.E.Asia
Calymperes subintegrum Broth.	2, 6b, 7, 9	S.E.Asia
Calymperes taitense (Sull.) Mitt.	2, 3, 5, 6b, 9	S.E.Asia
Calymperes tenerum Müll.Hal.	1, 2, 3, 4, 5, 7, 9	S.E.Asia
Calyptothecium acutum (Mitt.) Broth.	1, 2	AU
Calyptothecium australinum (Mitt.) Paris	4	AU, **NS**
Calyptothecium humile (Mitt.) Broth.	1, 9	South America
Calyptothecium recurvulum (Broth.) Broth.	7	Melanesia

Calyptothecium subecastatum Dixon	3	WT
Calyptrochaeta apiculata (Hook. f. & Wilson) Vitt	7	S. America, NZ, Antarctic Islands
Calyptrochaeta brassii (E. B. Bartram) Streimann	4, 9	WT
Calyptrochaeta rotundifolia (Nog. & Z. Iwats.) Touw	7	S.E.Asia, **NR**
Camptochaete curvata Tangney	4 (rare)	AU
Camptochaete deflexa (Wilson) A. Jaeger	4, 9	NZ
Camptochaete excavata (Taylor) A. Jaeger	2, 3, 4, 5, 6b, 7, 9	AU
Campylopus catarractilis (Müll.Hal.) Paris	1, 2, 4, 5, 6a	Southern Africa, NZ
Campylopus clemensiae E.B. Bartram	4	S.E.Asia
Campylopus comosus (Schwägr.) Bosch & Sande Lac.	3, 4, 5, 8	S.E.Asia
Campylopus ericoides (Griff.) A. Jaeger	8	S.E.Asia -India
Campylopus flexuosus (Hedw.) Brid.	2, 3, 4, 7, 9	S.E.Asia, NZ
Campylopus flindersii Catches. & J.-P. Frahm	6a	AU
Campylopus introflexus (Hedw.) Brid.	4, 7, 9	Southern Hemisphere
Campylopus laxitextus Sande Lac.	2, 4, 9	S.E.Asia, New Caled
Campylopus pyriformis (Schultz) Brid.	4, 7	NZ, subtropics, N.Caled.
Campylopus robillardei Besch.	4, 6a, 7, 9	Tropical Africa
Campylopus sinensis (Müll.Hal.) J.-P. Frahm	3, 4, 9	S.E.Asia
Campylopus umbellatus (Schwägr. & Gaudichaud ex Arn.) Paris	1, 4, 5, 6a, 7, 9	S.E.Asia
Chaetomitrium tahitense (Sull.) Mitt.	3, 4, 9	S.E.Asia
Claopodium assurgens (Sull. & Lesq.) Cardot	1, 3	S.E.Asia
Clastobryum dimorphum (I. G. Stone) B. C. Tan, Z. Iwats. & D. H. Norris	7, 9	AU
Clastobryum epiphyllum (Renauld & Cardot) B. C. Tan &Touw	5, 6a	S.E.Asia
Cryphaea tenella (Schwägr.) Hornsch. ex Müll.Hal.	4	Tropical Pacific, NZ
Cryptogonium phyllogonioides (Sull.) Isov.	3	S.E.Asia
Cyathophorum bulbosum (Hedw.) Müll.Hal.	7	NZ.
Cyclodictyon blumeanum (Müll.Hal.) O.Kuntze	4, 7, 9	S.E.Asia , Pacific
Cyptodon muelleri (Hampe) M. Fleisch.	3, 4, 8	AU
Daltonia contorta Müll.Hal.	4, 7	S.E.Asia
Daltonia splachnoides (Sm.) Hook. & Taylor	7	NZ
Dawsonia longiseta Hampe?	4, 9	AU
Dawsonia polytrichoides R. Br.	4, 5, 9	AU
Dawsonia superba Grev. var. *pulchra* Zanten	4, 9	AU
Dicnemon calycinum (Hook.) Schwägr.	8	NZ
Dicranella dietrichiae (Müll.Hal.) A. Jaeger	4, 9	NZ
Dicranella euryphylla Dixon	4	WT
Dicranella pycnoglossa (Broth.) Kindb.	3, 4, 7, 8, 9	AU
Dicranoloma austroscoparium (Müll.Hal ex Broth.) Watts & Whitel.	4, 7, 9	WT
Dicranoloma braunii (Müll.Hal. Ex Bosch & Sande Lac.) Paris	9	S.E.Asia
Dicranoloma daymannianum E.B.Bartram	4, 5, 6a, 7	S.E.Asia
Dicranoloma dicarpum (Nees) Paris	4	S.E.Asia, NZ
Dicranoloma leichhardtii (Hampe) Watts & Whitel.	4, 5	AU
Dicranoloma menziesii (Taylor) Renauld	4, 7, 9	NZ, New Caled.
Dicranoloma robustum (Hook.f. & Wilson) Paris	7	NZ, sub-Antarctic Islands
Dicranoloma wattsii Broth.	4	AU
Diphyscium mucronifolium Mitt.	7, 9	S.E.Asia, **NR**
Distichophyllum crispulum (Hook. f. & Wilson) Mitt.	4, 5, 7, 9	NZ
Distichophyllum cuspidatum (Dozy & Molk.) Dozy & Molk.	3	S.E.Asia
Distichophyllum mittenii Bosch & Sande Lac.	4, 5, 6a	S.E.Asia
Ditrichum difficile (Duby) M. Fleisch.	2, 4, 5, 7	S.E.Asia, NZ
Eccremidium brisbanicum (Broth.) I. G. Stone & G. A. M. Scott	2	S.E.Asia, New Caled.
Eccremidium minutum (Mitt.) I. G. Stone & G. A. M. Scott	3	NZ, New Caled.
Eccremidium pulchellum (Hook. & Wilson) Müll.Hal.	2	NZ
Ectropothecium maritzii A. Jaeger	7, 8	S.E.Asia

Ectropothecium riparioides E. B. Bartram	4	AU
Ectropothecium umbilicatum var. *umbilicatum* (Müll.Hal.) Paris	4,7, 8	OC
Ectropothecium zollingeri (Müll.Hal.) A.Jaeger	4, 7,8	S.E.Asia
Entodon mackaviensis Müll.Hal.	4, 5	AU
Entodon plicatus Müll.Hal.	4, 6a, 9	S.E.Asia
Ephemeropsis tjibodensis K. J. Goebel	2, 4, 7, 9	S.E.Asia, NZ
Ephemerum fimbriatum Müll.Hal.	2, 6a	New Caled.
Erpodium coronatum (Hook. f. & Wilson) Mitt. var. *australiense* (I G. Stone) I.G. Stone	5	AU
Erpodium hodgkinsoniae (Hampe & Müll.Hal.)	1	Norfolk Island
Erpodium solmsiellaceum (Müll.Hal. & Broth.) I.G.Stone	2, 3	New Caled.
Eucamptodon muelleri var. *muelleri* Hampe & Müll.Hal.	2, 4, 5, 6a, 6b, 7, 8, 9	AU
Eucamptodon scalarirete (Dixon) B.C. Tan, H.P. Ramsay & W.B. Schofield	4, 5, 7, 9	AU
Euptychium setigerum (Sull.) Broth. subsp. *setigerum*	3	S.E.Asia
Eurhynchium laevisetum Gch.	4	AU
Exostratum blumei (Nees ex Hampe) L.T. Ellis	2, 7, 9	S.E.Asia
Fabronia australis Hook.	4, 9	NZ
Fallaciella gracilis (Hook. f. & Wilson) H.A.Crum	3, 4	NZ, S.E.Asia,
Fissidens altisetus Dix. [= *F. bogoriensis* according to Streimann & Klazenga (2002) but *F. bogoriensis* not known in Australia (pers. comm. I. Stone)]	9	AU ?
Fissidens asplenioides Hedw.	4	Asia
Fissidens autoicus Thér. & Broth.	4, 7	S.E.Asia
Fissidens badyinbarus I. G. Stone & Catches.	6b	WT
Fissidens bryoides Hedw. var. *schmidii* (Mull. Hal.) R.S. Chopra & S.S. Kumar	4	Asia
Fissidens cambewarrae Dixon	2	AU
Fissidens ceylonensis Dozy & Molk.	7	S.E.Asia, NZ
Fissidens crassinervis Sande Lac.	9	Asia
Fissidens crenulatus Mitt.	1, 6a	Indo-Burmese
Fissidens crispulus Brid.	1, 3, 4, 6a, 7, 9	Southern Africa, Japan
Fissidens curvatus Hornsch.	4	S.E.Asia
Fissidens dietrichiae Müll.Hal.	4	New Caled.
Fissidens flabellulus Thwaites & Mitt.	2, 3, 4, 6a	S.E.Asia, New Caled.
Fissidens flabellulus Thwaites & Mitt. var. *eachamensis* I. G. Stone	4	WT
Fissidens gardneri Mitt.	1, 9	S.E.Asia
Fissidens gymnocarpus I. G. Stone	9	AU
Fissidens henryae I. G. Stone	2	WT
Fissidens hollianus Dozy & Molk.	9	S.E.Asia
Fissidens holstii Broth.	8	S.E.Asia
Fissidens hyalinus Hook. & Wilson	4	S.E.Asia
Fissidens leptocladus Müll. Hall ex Rodway	2	NZ
Fissidens linearis Brid. var. *obscurirete* (Broth.) I. G. Stone	9	New Caled.
Fissidens oblatus I. G. Stone & Catches.	4	WT
Fissidens oblongifolius Hook. f. & Wilson	4	WT
Fissidens oblongifolius Hook. f. & Wilson var. *hyophilus* (Mitt.) Beever & I. G. Stone	2, 4, 7	AU
Fissidens pallidus Hook. f. & Wilson var. *pallidus*	4	NZ
Fissidens patulifolius Dixon	2	AU
Fissidens pellucidus Hornsch.	1, 4	Asia
Fissidens perobtusus Dixon (on termite mounds)	2, 9	AU
Fissidens polypodioides Hedw.	5	NR
Fissidens pseudopallidus I. G. Stone	8	WT
Fissidens punctulatus Sande Lac.	6a, 9	S.E.Asia

Fissidens rupicola Paris & Broth.	4, 6a, 9	OC
Fissidens serratus Müll.Hal.	9	S.E.Asia, New Caled.
Fissidens sufflatus I. G. Stone	7	WT
Fissidens tenellus Hook. f. & Wilson var. *australiensis* (A.Jaeger) Beever & I.G.Stone	4	AU, NR
Fissidens zollingeri Mont.	2, 3	S.E.Asia, OC
Floribundaria floribunda (Dozy & Molk.) M. Fleisch.	2, 4, 7, 9	S.E.Asia
Floribundaria pseudofloribunda M. Fleisch.	4, 9	S.E.Asia
Floribundaria walkeri (Renauld & Cardot) Broth.	4	Southern Africa, S.E.Asia
Funaria hygrometrica Hedw.	5, 6a, 9	Cosmopolitan
Garckea flexuosa (Griff.) Margad. & Nork.	7, 9, 8	S.E.Asia
Garovaglia elegans (Dozy & Molk.) Bosch & Sande Lac. subsp. *dietrichiae* (Müll.Hal.) During	1, 3, 4, 5, 6a, 7, 8, 9	S.E.Asia, OC
Gemmabryum acuminatum (Harv. In Hook.) J.R. Spence and H.P. Ramsay	4,	Pantropical, subtropical
*Gemmabryum apiculatum (*Schwägr.)J.R. Spence & H.P. Ramsay = *Bryum apiculatum* Schwägr.	1, 2, 3, 4, 6a, 7, 8, 9	S.E.Asia, OC, N.Z.
Gemmabryum australe (Hampe) J.R. Spence & H.P. Ramsay = *Bryum australe Hampe*	1,9	NZ, S.E.Asia
Gemmabryum chrysoneuron (Müll Hal.) J.R. Spence & H.P. Ramsay = *Bryum chrysoneuron Müll Hal.*	3,4,6,7	New Caled., Oc, NZ
Gemmabryum clavatum (Schimp.) J.R. Spence & H.P. Ramsay = *Bryum clavatum* (Schimp.) Müll.Hal.	4, 7, 8	S.E.Asia, N.Z., OC
Gemmabryum coronatum (Schwägr.) J.R. Spence & H.P. Ramsay = *Bryum coronatum* Schwägr.; = *B. subatropurpureum* Müll.Hal.	1, 4, 5	New Caled., NZ
Gemmabryum dichotomum (Hedw.) J.R. Spence & H.P. Ramsay = *Bryum dichotomum* Hedw; = *B. pimpamae* Müll.Hal.	4, 6a, 8	NZ, Subantarctic
Gemmabryum exile (Dozy & Molk.) J.R. Spence & H.P. Ramsay	4,7, 9	S.E.Asia, OC
Gemmabryum indicum (Dozy & Molk.) J.R. Spence & H.P. Ramsay	2, 3, 8, 9	S.E.Asia, OC
*Gemmabryum pachythecum (*Müll.Hal.) J.R. Spence & H.P. Ramsay =*Bryum pachytheca* Müll.Hal.	9	S.E.Asia, NZ
Gemmabryum preissianum (Hampe) J.R.Spence & H.P. Ramsay	2, 6, 9	AU
Gigaspermum repens (Hook.) Lindb.	4	Southern Africa, NZ
?Glossadelphus hermaphroditus M. Fleisch. [=*Chaetomitrium entodontoides* Broth. & Watts *Glossadelphus* = *Phyllodon* (see Buck 1987)	3	S.E.Asia
Grimmia pulvinata (Hedw.) Sm var. *africana* (Hedw.) Hook. f. & Wilson	8	NZ
Groutiella tomentosa (Hornsch.) Wijk & Margad.	4, 6a, 9	S.E.Asia
Hampeella concavifolia Hattaway & Norris (in prep.)	7, 9	WT, NR
Hampeella pallens (Sande Lac.) M. Fleisch.	4, 5, 6b, 7, 9	S.E.Asia
Herpetineuron toccoae (Sull. & Lesq.) Cardot	4, 7	Cosmopolitan
Himantocladium cyclophyllum (Müll.Hal.) M. Fleisch.	7, 9	S.E.Asia
Holomitrium perichaetiale (Hook.) Brid.	1, 2, 3, 4, 5, 6a, 7, 8, 9	NZ
Homaliodendron exiguum (Bosch & Sande Lac.) M. Fleisch.	1, 2, 4, 9	S.E.Asia
Homaliodendron flabellatum (Sm.) M. Fleisch.	4, 9	S.E.Asia
Hookeriopsis utacamundiana (Mont.) Broth.	5, 7, 9	S.E.Asia
Hyophila involuta (Hook.) A. Jaeger	2, 3, 4, 9	S.E.Asia
Hypnodendron comatulum (Geh. ex Broth.) Touw	2, 3, 4, 5, 6a, 7	WT
Hypnodendron spininervium (Hook.) A.Jaeger & Sauerb. subsp. *archeri* (Mitt.) Touw	4, 7, 8	AU
Hypnodendron vitiense Mitt. subsp. *australe* Touw	4, 5, 9	AU
Hypnodendron vitiense Mitt. subsp. *vitiense*	4, 7	S.E.Asia, OC
Hypnum cupressiforme Hedw.	2, 3, 4, 5, 8, 9	Cosmopolitan
Hypnum subchrysogaster (Broth.) Paris	7	AU
Hypopterygium tamarisci (Sw.) Brid. ex Müll.Hal.	4, 5, 6b	NZ
Isocladiella wattsii (Broth.) B.C. Tan, H.P. Ramsay & W.B. Schofield	7	WT

Isopterygium acuminatum Bosw.	4, 7, 8	AU, **NR**
Isopterygium albescens (Hook.) A. Jaeger	2, 4	S.E.Asia, OC, NZ
Isopterygium minutirameum (Müll.Hal.) A. Jaeger var. *brevifolium* (M.Fleisch.) E.B.Bartram	7	S.E.Asia, OC
Isopterygium minutirameum (Müll.Hal.) A. Jaeger var. *minutirameum*	2,3,6b,9	NZ
Isopterygium novae-valesiae Broth.	2,4,7	AU
Lembophyllum divulsum (Hook. f. & Wilson) var. *clandestinum* (Hook. f. & Wilson) Wijk & Margad.	7, 9	NZ
Leptobryum pyriforme (Hedw.) Wilson	5	NZ
Leptodictyum riparium (Hedw.) Warnst.	4	**NR**
Leptostomum erectum R. Br.	1, 2, 4	AU
Leptotrichella tenax (Müll.Hal.) Ochyra var. *longipes* (Müll.Hal.) Ochyra	9	AU
Leucobryum aduncum Dozy & Molk. var. *aduncum*.	2, 3, 4, 6a, 8, 9	S.E.Asia
Leucobryum aduncum Dozy & Molk. var. *scalare* (Müll.Hal.ex M.Fleisch) A.Eddy	1, 2, 4, 6a, 9	S.E.Asia, New Caled.
Leucobryum ballinense Broth.	3, 4, 5	AU
Leucobryum candidum (Brid. ex P. Beauv.) Wilson	2, 3, 4, 5, 6a, 6b, 7, 8, 9	Asia, New Caled., NZ,
Leucobryum chlorophyllosum Müll.Hal.	1, 4, 9	S.E.Asia, New Caled. **NR**
Leucobryum sanctum (Brid.) Hampe	2, 3, 4, 6a, 7, 8, 9	S.E.Asia
Leucobryum subchlorophyllosum Hampe	4, 6a, 7, 9	**NR**
Leucobryum wattsii Broth.	1, 2, 6a, 6b, 9	AU
Leucoloma [various undetermined species]	4, 6a, 7, 9	WT
Leucoloma molle (Müll.Hal.) Mitt.	4, 7	AU
Leuconium strumosum (Hornsch.) Mitt.	3, 4	S. Amererica, **NR**
Leucophanes angustifolium Renauld & Cardot	1, 3, 5, 7	Madagascar
Leucophanes candidum (Schwägr.) Lindb.	9	S.E.Asia, OC
Leucophanes glaucum (Schwägr.) Mitt.	2, 3, 7, 8, 9	S.E.Asia, OC
Leucophanes octoblepharoides Brid.	3, 4, 6b, 7, 8, 9	S.E.Asia, OC
Lopidium concinnum (Hook.) Wilson	2, 6b, 7, 9	South America, NZ
Lopidium struthiopteris (Brid.) M. Fleisch.	4, 5, 7	S.E.Asia, OC
Macgregorella indica (Broth.) W.R. Buck	4	S.E.Asia
Macrohymenium nitratum (Dozy & Molk.) M. Fleisch.	6b	S.E.Asia
Macromitrium archeri Mitt.	4, 7, 9	AU
Macromitrium aurescens Hampe	1, 4, 6a	AU
Macromitrium caloblastoides Müll.Hal.	1, 2, 4	AU
Macromitrium diaphanum Müll.Hal.	4	AU
Macromitrium dielsii Broth. ex Vitt & H.P. Ramsay	7	WT
Macromitrium exsertum Broth.	4, 7, 9	AU
Macromitrium funiforme Dixon	7, 9	WT
Macromitrium hemitrichodes Schwägr.	4, 9	AU
Macromitrium hortoniae Vitt & H.P. Ramsay	5	AU, **NR**
Macromitrium incurvifolium (Hook. & Grev.) Schwägr.	3, 9	OC
Macromitrium involutifolium (Hook. & Grev.) Schwägr. subsp. *involutifolium*	4, 5, 7	New Caled.
Macromitrium involutifolium (Hook. & Grev.) Schwägr. subsp. *ptychomitrioides* (Besch.) Vitt & H.P. Ramsay	4, 5, 6a, 7, 9	OC
Macromitrium leratii Broth. & Paris	4, 6a, 6b, 7, 9	AU
Macromitrium ligulaefolium Broth.	2, 3, 4, 5, 6a, 7, 8, 9	NZ, New Caled., OC.
Macromitrium microstomum (Hook. & Grev.) Schwägr.	1, 2, 3, 4, 7, 9	NZ, OC
Macromitrium repandum Müll.Hal.	1, 4, 5, 6a, 7, 8, 9	AU
Macromitrium stoneae Vitt & H.P. Ramsay	4	AU
Meiotheciella papillosa (Broth.) B.C. Tan, H.P. Ramsay & W.B. Schofield	5	S.E.Asia, New Caled. NS
Meiothecium secundifolium Dixon	2	WT, NS

Meiothecium microcarpum (Hook.) Mitt. = *Meiothecium wattsii* (Broth.) Broth. [Australian specimens of *Meiothecium jagorii* (Müll.Hal.) Broth are this, earlier missidentified]	2, 6b, 9	S.E.Asia, New Caled., Oc.
Meiothecium tenellum Broth. & Paris	3, 4, 8	S.E.Asia
Mesochaete taxiforme (Hampe) Watts & Whitel.	4, 5, 9	AU
Mesochaete undulata Lindb.	1, 5	AU
Mesonodon flavescens (Hook.) W.R. Buck	4	S.E.Asia
Meteoriopsis reclinata (Müll.Hal.) M. Fleisch. ex Broth.	3, 4, 7, 8, 9	S.E.Asia
Meteorium polytrichum Dozy & Molk	3, 4, 5, 6a, 7, 9	S.E.Asia
Mittenia plumula (Mitt.) Lindb.	5	NZ, PNG, NR
Mitthyridium constrictum (Sull.) H.Rob.	3, 7, 9	S.E.Asia
Mitthyridium crassum (Broth.) H.Rob.	2, 9	S.E.Asia
Mitthyridium fasciculatum (Hook. & Grev.) H.Rob.	2, 3, 4, 7, 9	S.E.Asia
Mitthyridium flavum (Müll.Hal.) H.Rob.	1, 2, 3, 6a, 7, 8, 9	S.E.Asia
Mitthyridium leucoloma (Müll.Hal.) H.Rob.	3	S.E.Asia
Mitthyridium papuanum (Broth.) H.Rob.	2, 3, 7, 9	S.E.Asia
Mitthyridium perundulatum (Broth.) H.Rob.	3, 7, 9	S.E.Asia
Mitthyridium repens (Harv.) H.Rob.	2, 3, 7, 9	S.E.Asia
Mitthyridium subluteum (Müll.Hal.) H.K. Nowak	1, 2, 3, 5, 9	S.E.Asia
Muellerobryum whiteleggei (Broth.) M. Fleisch.	1, 2, 3, 4, 5, 6b, 7, 9	AU
Myurium rufescens (Reinw. & Hornsch.) M. Fleisch. subsp. *purpuratum* (Mitt.) Maschke [*Oedicladium* — no combination available]	4, 7, 9	S.E.Asia, Oc
Nanobryum thorsbornei I. G. Stone = *Fissidens thorsbornei* (I. G. Stone) Brugg.-Nann.	3, 5, 6a, 9	New Caled.
Neckeropsis lepineana (Mont.) M. Fleisch.	1, 4, 9	S.E.Asia
Neckeropsis nanodisticha (Geh.) M. Fleisch.	1, 2	S.E.Asia
Neolindbergia vitiensis (E.B.Bartram) Enroth	9	S.E.Asia
Notoligotrichum australe (Hook. f. & Wilson) G.L.Sm.	4	NZ
Octoblepharum albidum Hedw.	1, 2, 4, 6a, 6b, 9	S.E.Asia
Oedicladium rufescens (Reinw. & Hornsch.) M. Fleisch. subsp. *rufescens* [see *Myurium* also]	4, 6b, 9	S.E.Asia, OC
Orthomnion elimbatum (Nog.) T. J. Kop.	3, 4, 9	PNG
Orthorrhynchium elegans (Hook. f. & Wilson) Reichhardt subsp. *cymbifolioides* (Müll.Hal.) Lin.	7	S.E.Asia. NZ
Papillaria crocea (Hampe) A. Jaeger	4, 5, 6a, 8, 9	S.E.Asia. NZ
Papillaria flexicaulis (Wilson) A. Jaeger	4, 5	S.E.Asia. New Caled.
Papillaria leuconeura (Müll.Hal.) A. Jaeger	6a, 9	S.E.Asia
Papillaria nitens (Hook. f. & Wilson) Sainsbury	3, 4, 5, 6a, 6b, 7, 9	NZ, New Cal.
Pelekium gratum (P.Beauv.) Touw	1, 6b, 7	S.E.Asia
Pelekium investe (Mitt.) Touw	4	S.E.Asia, NR
Pelekium synoicum (Touw) Touw	4,7,8	S.E.Asia
Philonotis hastata (Duby) Wijk & Margad.	3, 4, 8, 9	S.E.Asia, NZ
[*Philonotis pseudomollis* (Müll.Hal.) A. Jaeger (? *P. tenuis*)]	4, 7	AU
Philonotis tenuis (Taylor) Reichardt	4, 7	NZ
Philonotis thwaitesii Mitt.	9	Asia, S.E.Asia, S.America, NR
Pinnatella alopecuroides (Mitt.) M. Fleisch.	7, 9	S.E.Asia
Pinnatella kuehliana (Bosch & Sande Lac.) M. Fleisch.	2, 4, 6a	S.E.Asia, OC
Platyhypnidium austrinum (Hook. f. & Wilson) M. Fleisch.	7	NZ
Platyhypnidium muelleri (A. Jaeger) M. Fleisch.	7	PNG, Hawaii, NR
Pogonatum neesii (Müll.Hal.) Dozy	4	S.E.Asia, OC
Pogonatum tubulosum Dixon	9	S.E.Asia
Polytrichum juniperinum Hedw.	4	S.E.Asia
Powellia breviseta (E. B. Bartram) Zanten	1, 2 (in Flora)	New Caled., OC, NR
Powellia involutifolia Mitt.	2, 5, 7	S.E.Asia, OC

Pseudohypnella verrucosa (Dozy & Molk.) M. Fleisch.	3, 7	S.E.Asia
Pseudospiridentopsis horrida (Mitt. ex Cardot) M. Fleisch.	7	WT
Pseudosymblepharis bombayensis (Müll.Hal.) P. Sollman	9	Asia, S.E.Asia, NR
Pterobryella breviacuminata Besch.	4, 9	OC
Pterobryidium australe Broth. & Watts	4	AU
Ptychomitrium australe (Hampe) A. Jaeger	4	NZ
Ptychomnion aciculare (Brid.) Mitt.	7	NZ, NR
Pyrrhobryum latifolium (Bosch. & Sande Lac.) Mitt.	4, 5, 6a, 9	S.E. Asia
Pyrrhobryum medium (Besch.) Manuel	4, 5, 7	S.E.Asia, OC
Pyrrhobryum paramattense (Müll.Hal.) Manuel ?doubtful species (Frahm 2003)	1, 3, 4, 6b, 7, 9	S.E.Asia, NZ
Pyrrhobryum spiniforme (Hedw.) Mitt.	1, 4, 6a, 7, 9	S.E.Asia
Racopilum cuspidigerum (Schwägr.) Ångstr. var. *convolutaceum* (Müll.Hal.) Zanten & Dijkstra	3, 7	OC, NZ
Racopilum cuspidigerum (Schwägr.) Ångstr. var. *cuspidigerum*	7	S.E.Asia, OC
Radulina hamata (Dozy & Molk.) W.R.Buck & B.C. Tan	1, 3, 5, 8, 9	S.E.Asia, OC
Rhaphidorrhynchium amoenum (Hedw.) M. Fleisch. var. *amoenum*	9	NZ
Rhizogonium graeffeanum (Müll.Hal.) A. Jaeger	4, 7, 9	S.E.Asia
Rhodobryum aubertii (Schwägr.) Thér.	4, 6a, 7, 9	S.E.Asia
Rhynchostegium distratum (Hampe) A. Jaeger	4	AU
Rhynchostegium nanopennatum (Broth.) Kindb.	7	WT
Rhynchostegium tenuifolium (Hedw.) Reichhardt var. *tenuifolium*	4	S.E.Asia, OC, NZ
Rosulabryum albolimbatum (Hampe) J.R. Spence	2, 4,	AU
Rosulabryum billarderi (Schwägr.) J.R. Spence	1, 4, 5, 6a, 7, 9	OC
Rosulabryum capillare (Hedw.) J.R. Spence	9	Cosmopolitan
Rosulabryum epiphyticum J.R. Spence & H.P. Ramsay	2	AU, NS
Rosulabryum lamingtonicum J.R. Spence & H.P. Ramsay	3	AU
Rosulabryum leptothrix (Mull. Hal.) J.R. Spence	2, 9	AU
Rosulabryum subfasciculatum (Hampe) J.R. Spence	1, 2, 3, 4, 5, 6a, 8, 9	New Caled.
Rosulabryum subtomentosum (Hampe) J.R. Spence	2, 4	NZ
Rosulabryum torquescens (Bruch ex De Not) J.R.Spence	1	Cosmopolitan
Rosulabryum tuberosum (Mohamed & Damanhuri) J.R. Spence	3	S.E.Asia
Rosulabryum wightii (Mitt.) J.R. Spence	1, 2, 4, 5, 6a, 7, 8, 9	India
Schlotheimia brownii Schwägr.	4, 6a, 7, 9	AU
Schlotheimia funiformis Taylor ex Dixon	4, 6a	AU
Schoenobryum concavifolium (Griff.) Gangulee	4	S.E.Asia
Sclerodontium clavinerve (Müll.Hal.) H.A.Crum	3, 4	AU
Sclerodontium pallidum (Hook.) Schwägr. subsp. *pallidum*	4, 9	NZ
Sematophyllum homomallum (Hampe) Broth.	2 (rare)	S.E.Asia, OC
Sematophyllum subhumile (Müll.Hal.) M. Fleisch. var. *subhumile*	2, 4, 5, 6, 7, 8, 9	S.E.Asia, NZ, OC
Sematophyllum subhumile (Müll.Hal.) M. Fleisch. var. *contiguum* (Mitt.) B.C. Tan, W.B. Schofield & H.P. Ramsay	6,7	OC, NZ
Sematophyllum subpinnatum (Brid.) E. Britton	1, 2, 3, 4, 5, 6, 9	S.E.Asia, OC
Sorapilla papuana Broth. & Geh.	9	S.E.Asia
Sphagnum perichaetiale Hampe	3	S.E.Asia, NZ
Stereophyllum radiculosum (Hook.) Mitt.	4, 5	AU
Syrrhopodon albovaginatus Schwägr.	7, 9	S.E.Asia
Syrrhopodon aristifolius Mitt.	2, 9	S.E.Asia
Syrrhopodon armatus Mitt.	2, 3, 4, 6a, 7, 8, 9	S.E.Asia
Syrrhopodon ciliatus (Hook.) Schwägr.	'rare' (Reese & Stone 1995)	S.E.Asia, OC
Syrrhopodon confertus Sande Lac.	3, 7, 9	S.E.Asia
Syrrhopodon croceus Mitt.	3, 7, 9	S.E.Asia
Syrrhopodon cyrtocanthos Reese	9	WT
Syrrhopodon involutus Schwägr.	2, 3, 6a	S.E.Asia

Syrrhopodon muelleri (Dozy & Molk.) Sande Lac.	3, 4, 7, 8, 9	S.E.Asia
Syrrhopodon parasiticus (Brid.) Besch.	6a, 7, 9	S.E.Asia
Syrrhopodon platycerii Mitt.	2, 4, 9	AU
Syrrhopodon prolifer Schwägr. var. *mossmanensis* Reese	9	WT
Syrrhopodon prolifer Schwägr. var. *prolifer*	9	S.E.Asia
Syrrhopodon stoneae Reese	6b, 7	WT
Syrrhopodon trachyphyllus Mont.	1, 6a, 6b, 8, 9	S.E.Asia
Syrrhopodon tristichus Nees ex Schwägr.	7, 9	S.E.Asia
Taxiphyllum taxirameum (Mitt.) M. Fleisch.	4	S.E.Asia, OC
Taxithelium instratum (Brid.) Broth.	1,5, 7, 9	S.E.Asia
Taxithelium kerianum (Broth.) Broth.	3, 6a, 7, 9	S.E.Asia
Taxithelium merillii Broth.	3, 6b, 7, 8, 9	S.E.Asia
Taxithelium muscicola (Broth.) B.C.Tan, H.P.Ramsay & W.B.Schofield	2, 7, 9,	AU
Taxithelium nepalense (Schwägr.) Broth.	4, 5, 7	S.E.Asia, tropical Africa
Taxithelium planum (Brid.) Mitt.	4, 5	S.E.Asia, tropical Africa
Thamnobryum ellipticum (Bosch & Sande Lac.) W. Schultze-Motel	3	S.E.Asia
Thamnobryum pandum (Hook. f. & Wilson) I. G. Stone & G.A.M. Scott	9	NZ
Thamnobryum pumilum (Hook.f. & Wilson) Nieuwl.	7	NZ,
Thuidiopsis sparsa (Hook. f. & Wilson) Broth.	4, 9	NZ,
Thuidium cymbifolium (Dozy & Molk.) Dozy & Molk.	1, 3, 4, 6b, 9	New Caled., OC,NZ
Touwia laticostata Ochyra	7	WT
Trachycarpidium brisbanicum (Mull. Hal.) I.G. Stone	1, 2	AU
Trachyloma diversinerve Hampe	4, 9	NZ
Trachyloma indicum Mitt.	4	S.E.Asia
Trachyloma planifolium (Hedw.) Brid.	4, 5, 9	NZ
Trachyphyllum inflexum (Harv.) A. Gepp.	1, 8	S.E.Asia
Trachypus humilis Lindb.	4	S.E.Asia, OC
Trachythecium verrucosum (A.Jaeger) M.Fleisch.	4	S.E.Asia, OC
Trematodon baileyi Broth.	9	AU
Trematodon longescens Müll.Hal.	7, 8	AU
Trematodon longicollis Michx.	8	NR
Trematodon suberectus Mitt.	4	NZ
Trichosteleum boschii (Dozy & Molk.) A. Jaeger	7	S.E.Asia, O
Trichosteleum ruficaule (Thwaites & Mitt.) B.C. Tan	2, 4, 7, 9,	S.E.Asia, OC
Trichosteleum subfalcatulum (Broth. & Watts) B.C. Tan, W.B. Schofield & H.P. Ramsay	1, 2, 4, 6a,	AU
Trichosteleum wattsii (Paris) B.C. Tan, W.B. Schofield & H.P. Ramsay	2, 6b	AU
Trichostomum brachydontium Bruch.	4	S.E.Asia
Trismegistia rigida (Mitt.) Broth.	9	S.E.Asia
Vesicularia rivalis Broth.	5, 9	AU
Viridivellus pulchellum I. G. Stone	3, 5, 7	AU
Warburgiella leptorhynchoides (Mitt.) M.Fleisch.	7, 9	S.E.Asia
Warburgiella leucocytus (Müll.Hal.) B.C. Tan, W.B. Schofield & H.P. Ramsay	1, 4, 7	NZ
Weissia balansae (Müll.Hal.) R.H.Zander	1, 2	New Caled.
Weissia controversa Hedw.	4	Cosmopolitan
Weissia platystegia (Dixon) A. Eddy = *Astomum platystegium* reported by Norris & Koponen (1989)	5	S.E.Asia
Wijkia extenuata (Brid.) H.A.Crum	1, 2, 4, 6a 7, 9	New Caled. NZ
Wilsoniella karsteniana Müll.Hal.	8	WT
Zygodon intermedius Bruch & Schimp.	4	NZ

Note: For one taxon, *Gemmabryum*, we are using the name to be published in the Flora of Australia treatment in volume 51 (in press 2005).

Appendix 2. Alphabetic list of genera with families

Acanthorrhynchium	Sematophyllaceae
Achrophyllum	Hookeriaceae
Acroporium	Sematophyllaceae
Aerobryopsis	Meteoriaceae
Anoectangium	Pottiaceae
Archidium	Archidiaceae
Arthrocormus	Calymperaceae
Barbellopsis	Meteoriaceae
Barbula	Pottiaceae
Bartramia	Bartramiaceae
Bescherellia	Cyrtopodaceae
Brachymenium	Bryaceae
Brachythecium	Brachytheciaceae
Braithwaitea	Trachylomataceae
Breutelia	Bartramiaceae
Bryobrothera	Adelotheciaceae
Bryum	Bryaceae
Buxbaumia	Buxbaumiaceae
Caduciella	Neckeraceae
Callicostella	Pilotrichaceae
Calymperes	Calymperaceae
Calyptothecium	Pterobryaceae
Calyptrochaeta	Daltoniaceae
Camptochaete	Lembophyllaceae
Campylopus	Dicranaceae
Chaetomitrium	Symphyodontaceae
Claopodium	Leskeaceae
Clastobryum	Sematophyllaceae
Cryphaea	Cryphaeaceae
Cryptogonium	Pterobryaceae
Cyathophorum	Hookeriaceae
Cyclodictyon	Pilotrichaceae
Cyptodon	Cryphaeaceae
Daltonia	Daltoniaceae
Dawsonia	Polytrichaceae
Dicnemon	Dicnemonaceae
Dicranella	Dicranaceae
Dicranoloma	Dicranaceae
Diphyscium	Diphysciaceae
Distichophyllum	Daltoniaceae
Ditrichum	Ditrichaceae
Eccremidium	Ditrichaceae
Ectropothecium	Hypnaceae
Entodon	Entodontaceae
Ephemeropsis	Daltoniaceae
Ephemerum	Ephemeraceae
Erpodium	Erpodiaceae
Eucamptodon	Dicnemonaceae
Euptychium	Garovagliaceae
Eurhynchium	Brachytheciaceae
Fabronia	Fabroniaceae
Fallaciella	Lembophyllaceae
Fissidens	Fissidentaceae
Floribundaria	Meteoriaceae
Funaria	Funariaceae
Garckea	Ditrichaceae
Garovaglia	Garovagliaceae
*Gemmabryum**	Bryaceae
Gigaspermum	Gigaspermaceae
Glossadelphus	Hypnaceae
Grimmia	Grimmiaceae
Groutiella	Orthotrichaceae
Hampeella	Ptychomniaceae
Herpetineuron	Anomodontaceae
Himantocladium	Neckeraceae
Holomitrium	Dicranaceae
Homaliodendron	Neckeraceae
Hookeriopsis	Pilotrichaceae
Hyophila	Pottiaceae
Hypnodendron	Hypnodendraceae
Hypnum	Hypnaceae
Hypopterygium	Hypopterygiaceae
Isocladiella	Sematophyllaceae
Isopterygium	Hypnaceae
Lembophyllum	Lembophyllaceae
Leptobryum	Meesiaceae
Leptodictyum	Amblystegiaceae
Leptostomum	Leptostomataceae
Leptotrichella	Dicranaceae
Leucobryum	Leucobryaceae
Leucoloma	Dicranaceae
Leucomium	Leucomiaceae
Leucophanes	Calymperaceae
Lopidium	Hypopterygiaceae
Macgregarella	Myriniaceae
Macrohymenium	Sematophyllaceae
Macromitrium	Orthotrichaceae
Meiotheciella	Sematophyllaceae
Meiothecium	Sematophyllaceae
Mesochaete	Rhizogoniaceae
Mesonodon	Entodontaceae
Meteoriopsis	Meteoriaceae
Meteorium	Meteoriaceae
Mittenia	Mitteniaceae
Mitthyridium	Calymperaceae
Muellerobryum	Pterobryaceae
Myurium	Myuriaceae
Nanobryum	Nanobryaceae
Neckeropsis	Neckeraceae
Neolindbergia	Pterobryaceae
Notologotrichum	Polytrichaceae
Octoblepharum	Calymperaceae
Oedicladium	Myuriaceae
Orthomnion	Mniaceae
Orthorrhynchium	Orthorrhynchiaceae
Papillaria	Meteoriaceae
Pelekium	Thuidiaceae
Philonotis	Bartramiaceae
Pinnatella	Neckeraceae
Platyhypnidium	Brachytheciaceae
Pogonatum	Polytrichaceae
Polytrichum	Polytrichaceae
Powellia	Racopilaceae
Pseudohypnella	Sematophyllaceae
Pseudospiridentopsis	Meteoriaceae
Pseudosymblepharis	Pottiaceae
Pterobryella	Pterobryellaceae
Pterobryidium	Pterobryaceae
Ptychomitrium	Ptychomitriaceae
Ptychomnion	Ptychomniaceae
Pyrrhobryum	Rhizogoniaceae
Racopilum	Racopilaceae
Radulina	Sematophyllaceae
Rhaphidorrhynchium	Sematophyllaceae
Rhizagonium	Rhizogoniaceae
Rhodobryum	Bryaceae
Rhynchostegium	Brachytheciaceae
Rosulabryum	Bryaceae
Schlotheimia	Orthotrichaceae
Schoenobryum	Cryphaeaceae
Sclerodontium	Dicranaceae
Sematophyllum	Sematophyllaceae
Sorapilla	Sorapillaceae
Sphagnum	Sphagnaceae
Stereophyllum	Stereophyllaceae
Syrrhopodon	Calymperaceae

Taxiphyllum	Hypnaceae
Taxithelium	Sematophyllaceae
Thamnobryum	Neckeraceae
Thuidiopsis	Thuidiaceae
Thuidium	Thuidiaceae
Touwia	Neckeraceae
Trachycarpidium	Pottiaceae
Trachyloma	Trachylomataceae
Trachyphyllum	Pterigynandraceae
Trachypus	Meteoriaceae
Trachythecium	Hypnaceae
Trematodon	Bruchiaceae
Trichosteleum	Sematophyllaceae
Trichostomum	Pottiaceae
Trismegistia	Sematophyllaceae
Vesicularia	Hypnaceae
Viridivellus	Viridivelleraceae
Warburgiella	Sematophyllaceae
Weissia	Pottiaceae
Wijkia	Sematophyllaceae
Wilsoniella	Ditrichaceae
Zygodon	Orthotrichaceae

Appendix 3. Index to genera and families (Shaw & Goffinet 2000, earlier classification in square brackets. * = new taxonomy).

Adelotheciaceae [Hookeriaceae]	*Bryobrothera*
Amblystegiaceae	*Leptodictyum*
Anomodontaceae	*Herpetineuron*
Archidiaceae	*Archidium*
Bartramiaceae	*Bartramia* *Breutelia* *Philonotis*
Brachytheciaceae	*Brachythecium* *Eurhynchium* *Platyhypnidium* *Rhynchostegium*
Bruchiaceae	*Trematodon*
Bryaceae	*Brachymenium* *Bryum* *Gemmabryum** *Rhodobryum* *Rosulabryum*
Buxbaumiaceae	*Buxbaumia*
Calymperaceae	*Arthrocormus* *Calymperes* *Exostratum* *Leucophanes* *Mitthyridium* *Octoblepharum* *Syrrhopodon*
Cryphaeaceae	*Cryphaea* *Cyptodon* *Schoenobryum*
Cyrtopodaceae	*Bescherellia*
Daltoniaceae [Hookeriaceae] [Hookeriaceae]	*Calyptrochaeta* *Daltonia* *Distichophyllum* *Ephemeropsis*
Dicnemonaceae	*Dicnemon* *Eucamptodon*
Dicranaceae	*Campylopus* *Dicranella* *Dicranoloma* *Holomitrium* *Leptotrichella* *Leucoloma* *Sclerodontium*
Diphysciaceae	*Diphyscium*
Ditrichaceae	*Ditrichum* *Eccremidium* *Garckea* *Wilsoniella*
Entodontaceae	*Entodon* *Mesonodon*
Ephemeraceae	*Ephemerum*
Erpodiaceae	*Erpodium*
Fabroniaceae	*Fabronia*
Fissidentaceae	*Fissidens*
Funariaceae	*Funaria*
Garovagliaceae	*Euptychium* *Garovaglia*
Gigaspermaceae	*Gigaspermum*
Grimmiaceae	*Grimmia*
Hookeriaceae	*Achrophyllum* *Cyathophorum*
Hypnaceae	*Ectropothecium* *Glossadelphus* *Hypnum* *Isopterygium* *Taxiphyllum* *Trachythecium* *Vesicularia*
Hypnodendraceae	*Hypnodendron*
Hypopterygiaceae	*Hypopterygium* *Lopidium*
Lembophyllaceae	*Camptochaete* *Fallaciella* *Lembophyllum*
Leptostomataceae	*Leptostomum*
Leucobryaceae	*Leucobryum*
Leucomiaceae	*Leucomium*
Meesiaceae	*Leptobryum*
Meteoriaceae	*Aerobryopsis* *Barbellopsis* *Floribundaria* *Meteoriopsis* *Meteorium* *Papillaria* *Pseudospiridentopsis* *Trachypus*

Mitteniaceae	*Mittenia*
Mniaceae	*Orthomnion*
Myriniaceae	*Macgregorella*
Myuriaceae	*Myurium*
	Oedicladium
Nanobryaceae [Fissidentaceae]	*Nanobryum*
Neckeraceae	*Caduciella*
	Himantocladium
	Homaliodendron
	Neckeropsis
	Pinnatella
	Thamnobryum
	Touwia
Orthorrhynchiaceae	*Orthorrhynchium*
Orthotrichaceae	*Groutiella*
	Macromitrium
	Schlotheimia
	Zygodon
Pilotrichaceae [Hookeriaceae]	*Callicostella*
	Cyclodictyon
	Hookeriopsis
Polytrichaceae	*Dawsonia*
	Notoligotrichum
	Pogonatum
	Polytrichum
Pottiaceae	*Anoectangium*
	Barbula
	Hyophila
	Pseudosymblepharis
	Trachycarpidium
	Trichostomum
	Weissia
Pterigynandraceae	*Trachyphyllum*
Pterobryaceae	*Calyptothecium*
	Cryptogonium
	Muellerobryum
	Neolindbergia
	Pterobryidium

Pterobryellaceae	*Pterobryella*
Ptychomitriaceae	*Ptychomitrium*
Ptychomniaceae	*Hampeella*
	Ptychomnion
Racopilaceae	*Powellia*
	Racopilum
Rhizogoniaceae	*Mesochaete*
	Pyrrhobryum
	Rhizogonium
Sematophyllaceae	*Acanthorrhynchium*
	Acroporium
	Clastobryum
	Isocladiella
	Macrohymenium
	Meiotheciella
	Meiothecium
	Pseudohypnella
	Radulina
	Rhaphidorrhynchium
	Sematophyllum
	Taxithelium
	Trichosteleum
	Trismegistia
	Warburgiella
	Wijkia
Sorapillaceae	*Sorapilla*
Sphagnaceae	*Sphagnum*
Stereophyllaceae	*Stereophyllum*
Symphyodontaceae [Hookeriaceae]	*Chaetomitrium*
Thuidiaceae	*Pelekium*
	Thuidiopsis
	Thuidium
Trachylomataceae	*Braithwaitea*
	Trachyloma
Viridivelleraceae	*Viridivellus*

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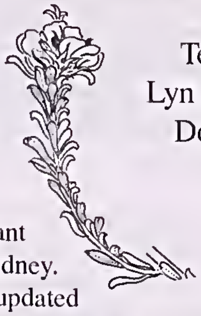
New completey revised edition



Teresa James
Lyn McDougall
Doug Benson

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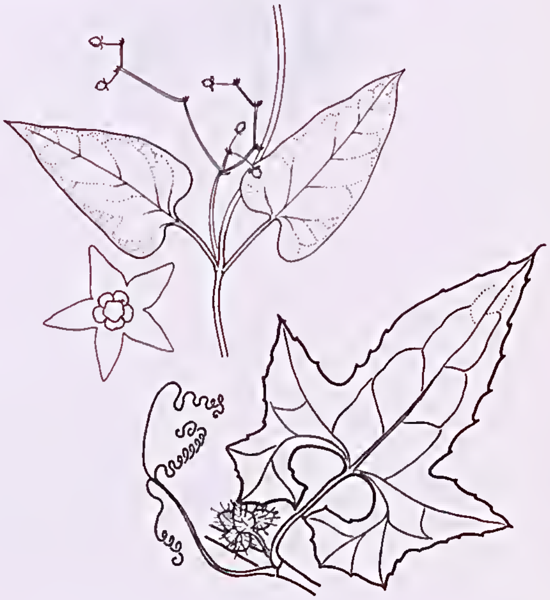

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Volume 8(3): 285–408 2004

Flora and vegetation of Montagu Island — past and present
Petrus C. Heyligers and Laurie G. Adams 285

Floristic patterns along an east–west gradient in grassy box woodlands of Central New South Wales
Suzanne M. Prober and K.R. Thiele 306

Drought-related dieback in four subalpine shrub species, Bogong High Plains, Victoria
John W. Morgan 326

Vegetation of Werakata National Park, Hunter Valley, New South Wales
Stephen A.J. Bell 331

Fire response syndromes of shrubs in grassy woodlands in the New England Tableland Bioregion
Kirsten J.E. Knox and Peter Clarke 348

A regional examination of the mistletoe host species inventory
Paul Owen Downey 354

Floristic patterns in coastal rainforest of Shoalwater Bay, Central Queensland
Peter McCarthy, Peter Clarke and Jeremy Bruhl 362

Habit, distribution and the phytogeographical affinities of mosses in the Wet Tropics bioregion, north-east Queensland, Australia
Helen P. Ramsay and Andi Cairns 371